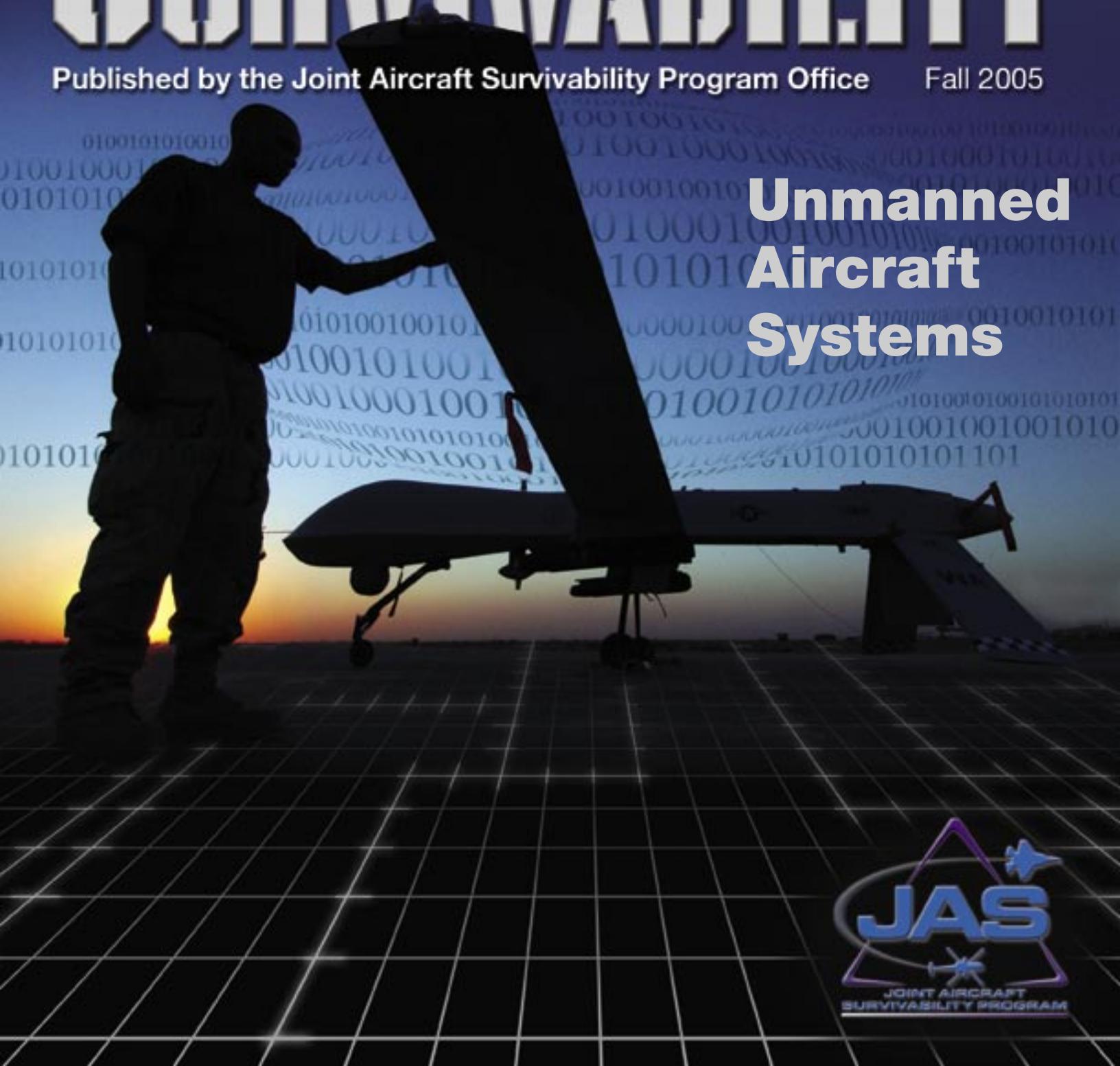


# AIRCRAFT SURVIVABILITY

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Fall 2005

## Unmanned Aircraft Systems



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The Joint Aircraft Survivability Program Office (JASPO) is pleased to recognize Kelly J. Kennedy for Excellence in Survivability. Kelly is the group leader for Vulnerability Analysis and Live Fire Test and Evaluation (LFT&E) in the Operational Analysis Branch of the Aeronautical Systems Center's Design, Analysis, and Simulation Division (ASC/ENMM), Wright Patterson Air Force Base (AFB), OH.

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by *Pete Bartolomeo*

With this new concept of non expendable UAVs, it is necessary to increase their survivability. In recent years, the Joint Aircraft Survivability Program Office (JASPO) has sponsored two projects to achieve this goal: "Miniature Radar Warning Receiver for UAVs," and "Acoustic Reduction for UAVs."

## 28 Influence of Unmanned Aircraft System (UAS) Survivability on System Life Cycle Cost

by *Dr. Gregory J. Born, David H. Hall, and Charles M. Pedriani*

Unmanned Aircraft Systems (UAS) are being considered for an ever widening range of missions, which has resulted in a growth of platform types and quantities, mission roles and equipment, and expanding operating environments. Because of system cost and/or mission criticality, survivability is becoming an important system attribute for many of these applications. As the trade space for survivability grows, approaches are required to guide developers to the best survivability solution for a given platform, mission, and threat or operational environment. This article is an overview of the methodology that SURVICE Engineering Company has been developing to assist decision makers in identifying the survivability alternatives that provide the lowest life cycle cost while meeting the operational requirements.

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# News Notes

■ by Mr. Dennis Lindell



Global Hawk

## UAS Roadmap Adopts New Terminology

The Unmanned Aircraft Systems (UAS) Roadmaps has been published and is available at <http://www.acq.osd.mil/uas/>. The roadmap adopted the new terminology unmanned aircraft (UA) rather than unmanned aerial vehicle (UAV) when referring to the flying component of an unmanned aircraft system (UAS) to more clearly emphasize that the aircraft is only one component of the total system. The purpose of the roadmap is "to stimulate the planning process for U.S. military UA development over the period from 2005-2030. It is intended to assist DoD decision makers in developing a long range strategy for UA development and acquisition in future Quadrennial Defense Reviews (QDRs) and other planning efforts, as well as to guide industry in developing UA technology." The JASPO supported AT&L in this endeavor by providing the survivability annex for this document which is included as Appendix K in the roadmap. The JASPO drew heavily upon the aircraft survivability community and the National Defense Industrial Association's (NDIA) Unmanned Aircraft Workshop results which are included in Kevin Crosthwaite's article in this issue.

**Editors Note:** Some of the articles in this issue were written before the UAS Roadmap changed the terminology so we have a mixture of both the old and the new terminology in this issue.

## Joint Aircraft Survivability Program Office (JASPO) Model Users Meeting (JMUM)

The Joint Aircraft Survivability Program Office (JASPO) Model Users Meeting (JMUM) 2005 was held on 14-17 June 2005 at the US Air Force Academy in Colorado Springs, CO. This was the ninth annual combined users meeting executed by the Survivability/Vulnerability Information Analysis Center (SURVIAC) and funded by JASPO. One hundred representatives participated in this year's meeting from various services and DoD contractors. JMUM is an excellent networking event for the JASPO and SURVIAC model users. This is an informative meeting for everyone who is interested in the JMUM model suite. The meeting promotes open discussion of hardware and software issues related to each of the JMUM models. The models included in the JMUM were as follows:

■ **ALARM**—Advanced Low-Altitude Radar Model

- **AJEM**—Advanced Joint Effectiveness Model
- **BLUEMAX**—Flight-Path Generator
- **BRAWLER**—Air-to-Air Combat Model
- **COVART**—Computation of Vulnerable Areas and Repair Times
- **ESAMS**—Enhanced Surface-to-Air Missile Simulation
- **FASTGEN**—Fast Shotline Generator
- **RADGUNS**—Radar-Directed Guns Simulation

The JMUM included one and a half days of general session and one and a half days of model breakout sessions. The general session began with a welcome briefing, followed by a JASPO briefing and a SURVIAC overview briefing. Technical briefs on model status and different modeling tools and capabilities were also presented. Following the general session, breakout sessions for the models were held. Model-specific topics were discussed during each session and included in-depth details on

the status of a model and its future schedules. The breakout sessions included formal presentations and working forums for users. The working groups also included Configuration Control Board (CCB) meetings. Users and CCB members discussed software change requests, which were voted on for incorporation into the model by the CCB members. Because users can provide information that would otherwise not be available for discussion, having them present during the CCB discussions has proven to be invaluable.



### **Matt Crouch Joins JASPO**

The JASPO welcomes Matt Crouch as the newest member of its staff. Mr. Crouch came to the JASPO in June 2005. Before that, he served as an Aerospace Engineer in the Utility Division of the Aviation Engineering Directorate at Redstone Arsenal, AL. Matt received his BS in Civil Engineering from the United States Military Academy in 1996. Before departing from active duty, he served in Iraq as a Blackhawk Maintenance Test Pilot assigned to the 101st Airborne Division. Matt is a welcome addition to the JASPO and will be Deputy Program Manager for Vulnerability Reduction.

### **Survivability Short Course**

The Joint Aircraft Survivability Program (JASP) completed a highly successful Aircraft Combat Survivability Short Course held at Wright Patterson Air Force Base, OH, 26–28 July 2005. Co-sponsored by the Survivability Vulnerability Information Analysis Center (SURVIAC), more than 100 attended the JASP funded introduction course. The course was held at the Secret classification level, and the agenda covered all aspects of the survivability discipline, including susceptibility

reduction, vulnerability reduction, and survivability modeling and simulation. The Joint Live Fire program was also covered, as were the efforts of the Joint Combat Assessment Team, sponsored by the JASP. A CD of all presentations and all course materials is being provided to each attendee. This is the second course sponsored by the JASP in the last three years. The first course was held in Williamsburg, VA. The JASP plans to offer this course annually as an outreach and educational tool to the survivability community. Planning for next year's course is under way. If you are interested in attending next year's course or have any questions, contact Darnell Marbury at JASPO, 703.607.3509, x10.

### **Survivability Model Credibility Enhancement Workshop**

Survivability Models & Simulations (M&S) are increasingly used to support key decisions affecting military system design, procurement, and employment. However, there are serious concerns about shortfalls in model credibility in three key areas—capability, accuracy, and usability. Because of the rising cost of military systems and the nation's extreme sensitivity to casualties, DoD's decision makers are likely to be receptive to making investments in the M&S that support survivability analyses that drive the acquisition process throughout DoD. But those decision makers require better information about the credibility of survivability M&S to make those investments.

On 17 May 2005, the National Defense Industrial Association (NDIA) Combat Survivability Division (CSD) conducted a workshop on Survivability Model Credibility Enhancement, hosted by the Institute for Defense Analyses (IDA). The Deputy Director, Operational Test & Evaluation/Live Fire Test & Evaluation (DDOT&E/LFT&E) sponsored the workshop. Leading experts in survivability M&S and key figures in the DoD were invited to participate.

The objective of the workshop was to explore the need for improvements in aircraft survivability M&S, to prioritize and recommend needed improvements, and to identify a series of actions and agents to pursue those recommendations.

The workshop was successful in identifying a set of high priority survivability model enhancements. The action items are focused on further defining and then implementing the highest payoff improvements. The key recommendation is to pursue a Program Objective Memorandum (POM) plus-up and additional resources to improve the community's aircraft survivability model set. This would lead to better survivability M&S in support of military system design, acquisition, and employment.

For a copy of the report and further information, please contact Kevin Crosthwaite at [crosthwaite\\_kevin@bah.com](mailto:crosthwaite_kevin@bah.com).



# Unmanned Aerial Vehicle (UAV) Survivability Enhancement Workshop

■ by Kevin R. Crosthwaite

**A** year ago, the National Defense Industrial Association's (NDIA) Combat Survivability Division (CSD) conducted a workshop on Unmanned Aerial Vehicle (UAV) survivability enhancement. The Institute for Defense Analyses (IDA), Arlington, VA, hosted the workshop, and the workshop was sponsored by the Director Of Operational Test & Evaluation/Live Fire Test & Evaluation (DOT&E/LFT&E). The NDIA CSD is known for conducting a series of annual Aircraft Survivability symposia at the Naval Postgraduate School in Monterey, CA, each fall. The CSD has decided to expand beyond the symposia format by hosting workshops to tackle specific issues, each workshop focusing on a specific topic and extending beyond the scope of only informing participants to tasking them to devise a plan of action and recommendations to implement needed changes.

## Background

The objective of the UAV Survivability Enhancement Workshop was to identify the highest payoff survivability enhancements and several candidate UAV systems that could be most receptive to incorporating survivability features. Beyond that objective, organizers and participants goal is that UAV system program managers review these findings and recommendations and implement several of the highest payoff survivability enhancements into their respective system designs. The workshop was planned and organized based on three premises:

- Current UAVs such as Global Hawk and Predator have had little or no survivability features incorporated into their designs. New UAV designs, such as the Joint Unmanned Combat Air System (J-UCAS), are incorporating

low observables to reduce susceptibility, but little design attention has been paid to reducing vulnerability.

- Available survivability techniques and technologies used in current manned aircraft could be considered to offer cost effective UAV survivability enhancement.
- Because of both the rising costs of platforms and sensor packages and recent combat losses, survivability enhancements are becoming cost effective for UAVs.

## Approach

Participants were selected by invitation only from among leading experts in various aspects of survivability techniques and key figures in the UAV community associated with some of its many programs. In the morning, 50 invited attendees heard an overview of survivability trade off considerations by Mr. David Hall. He presented a cost effectiveness "case for UAV survivability," pointing out that UAV missions are "the dull, the dirty, and the dangerous." As UAVs are proven effective, particularly on "the dangerous mission," they will face more determined threats and need more survivability, which can effectively "buy" its way onto a platform with increased cost effectiveness. Dave's trade off overview was followed by a presentation on current and developmental UAV systems by Mr. Ash Lafferty. He recommended various survivability features for different classes of UAVs. Then Hugh Griffis reviewed a wide variety of survivability enhancement features that are available to UAVs from manned aircraft development. He also recommended involving the Defense Advanced Research Projects Agency (DARPA) in developing a vulnerability reduction design guide.

Two breakout sessions were then convened to consider and rank the aspects of the eventual workshop recommendations. The first breakout session was led by Mr. Chris Cross and focused on survivability features. The session considered the effectiveness of the survivability techniques and balanced that against cost or operational impact; i.e., weight, for a UAV system. One discussion considered what elements to include in the definition of a UAV system. While loss of the ground control station, launch and recovery system, or data link could result in loss of a platform or mission capability, it was decided—for the purpose of the workshop—to focus only on the survivability of the mission platform. The second breakout session was led by Mr. Walt Whitesides and focused on UAV systems. This session considered which UAVs might be the best candidates for survivability enhancement.

At the conclusion of the breakout sessions and briefbacks, a final session was led by Mr. David Hall. This session reviewed the findings and focused on the practical matters of how to best encourage implementation of survivability enhancements. Even with the most cost effective survivability enhancements and the most receptive UAV systems, this is simply a recognition that even worthy change does not just happen by itself. Recommendations were discussed and defined. It was decided that workshop results would be formatted into an executive summary and will include the survivability and UAV priority tables, findings, and recommendations.

## Findings

The workshop was successful in achieving the objectives set forth for the breakout sessions that were held during the day of the workshop. Both breakout ses-

sions focused on the current status of UAV systems and survivability. There was consensus that survivability features should be at least considered in both UAV system development and as enhancements to existing systems.

The survivability session considered the missions and operating environments of key UAV platform types to identify relevant vulnerability reduction techniques and as the means to reduce susceptibility. This session completed an overview of survivability features in principle as potential enhancements to the five various types of UAV systems. The most worthy cost effective survivability enhancements from Table 1 were prioritized for each UAV type. The top enhancements on this list were deemed the most cost effective overall for incorporating into the respective UAV designs. This prioritized list is the distilled judgment of the survivability experts at the workshop, and this table provides an excellent starting point for any UAV program considering survivability enhancements.

The session on UAV systems considered the design, mission requirement, threat, and life cycle state of each sys-

tem as these factors might pertain to the potential willingness and need for a system to incorporate survivability enhancements. Combat incidents involving a specific or similar type UAV were considered. The inherent survivability of the specific design of a system was weighed, as was its potential for encountering threats. The perception of a UAV program and a user's willingness to consider survivability enhancements was another important factor.

This session resulted in a prioritized list of UAV systems that were considered to be best candidates to consider survivability enhancements. This list is shown in Table 2. The UAV systems deemed most receptive are listed at the top of the list. This is not to say that any system is less survivable than any other; rather, this list reflects the judgment of the UAV experts at this workshop: that the mission of this particular UAV could encourage the program office to favorably consider additional survivability, and that the program, because of a combination of design philosophy, operational history, and management, is most receptive to seriously considering survivability enhancements.

## Recommendations

Workshop attendees agreed on two recommendations:

- The first recommendation is that each UAV system should at least formally consider survivability enhancement. We are not single mindedly advocating survivability at all costs but are simply recommending that survivability be fairly and formally weighted along with other key system design tradeoffs.
- The workshop's second recommendation is to commission a study to take the workshop findings and further refine cost benefit survivability trade offs for a few specific UAV candidate systems. The Survivability/Vulnerability Information Analysis Center (SURVIAC) and the Joint Aircraft Survivability Program Office (JASPO) may be sources of information or execution. The Defense Science Board, the NDIA CSD, or JASPO may possibly conduct the study. These recommendations were forwarded to the appropriate Office of the Secretary of Defense (OSD) offices for action and the Under Secretary of Defense for Acquisition, Technology and Logistics endorsed the goals of the workshop and stated in a

Table 1. Prioritized survivability enhancement features

Priority Rank	UAV Category				
	Small	Tactical	Large	UCAV	Rotary
1	Acoustic Signature Reduction	Acoustic Signature Reduction	SA & Threat Avoidance	IR & RF Signature Reduction	Acoustic Signature Reduction
2	Visual Signature Reduction	Visual Signature Reduction	Infrared Countermeasures (IRCM) & Radio-frequency Countermeasures (RFCM)	Separation & Redundancy	RF Signature Reduction
3	Info Assurances	Infrared (IR) Signature Reduction	Separation & Redundancy	SA & Threat Avoidance	IR Signature Reduction
4	Situational Awareness (SA) & Threat Avoidance	Radio-frequency (RF) Signature Reduction	Passive Fire Suppression	IRCM & RFCM	Separation & Redundancy
5	Mission Planning & Tactics	SA & Threat Avoidance		Active Fire Suppression	IRCM & RFCM
6		Separation & Redundancy			System Ballistic Tolerance

Table 2. Candidate UAV systems to incorporate more survivability

Priority	UAV Category	System	Mission	Threats	Maturity
1	Large	Predator B Air Force (AF)	Hunter Killer	Tactical	In Development
1	Large	Broad Area Maritime Surveillance (BAMS) (Navy)	Intelligence, Surveillance, and Reconnaissance (ISR)	Tactical	In Development
1	UCAV	J-UCAS (AF)	Electronic Warfare (EW), Electronic Attack (EA), Suppression of Enemy Air Defenses (SEAD), Strike	Tactical	Developmental
1	UCAV	J-UCAS (Navy)	Carrier Based ISR, SEAD, Strike	Tactical	Developmental
1	Tactical	Extended Range Multi-Purpose (ERMP) (Army)	Hunter Killer, ISR, ACN/	Small, ADA, Tactical	Developmental
1	Rotorcraft	Fire Scout (Navy and Army)	ISR with Hunter Killer and ACN	Small, ADA, Tactical	Developmental
1	Rotorcraft	UCAR (Army)	Hunter Killer	Small, ADA, Tactical	Developmental
2	Large	Global Hawk (AF)	ISR	Strategic	Spiral Development and In Production, Deployed in Operation Iraqi Freedom (OIF)
2	Tactical	Shadow (Army)	ISR	Small, ADA, Tactical	In Production & Deployed
2	Tactical	Hunter (Army)	ISR with Hunter Killer	Small, ADA, Tactical	Deployed
2	Tactical	Predator (AF)	ISR and Hunter Killer	ADA, Tactical	In Production & Deployed
2	Small/Handheld	Silver Fox (Army/ USMC)	ISR	Small	In Development & Deployed
3	Tactical	Pioneer (USMC)	ISR	Small, ADA, Tactical	In Production & Deployed
3	Small/Handheld	Raven (Army)	ISR	Small	Deployed
3	Small/Handheld	Dragon Eye (USMC)	ISR	Small	Deployed
3	Small/Handheld	Pointer (Army)	ISR	Small	Deployed
3	Small/Handheld	Desert Hawk (AF)	ISR	Small	Deployed

1 = High 2 = Medium 3 = Low

27 January 2005 letter to the Services that "I request that you review your UAV programs to ensure that combat survivability and reliability are receiving adequate emphasis throughout the systems life cycles, especially during the initial design."

## Summary

This workshop has resulted in identifying the most cost effective survivability enhancements and the most receptive

UAV systems by which to consider these upgrades. Further action should focus on attempting to implement one or two of the highest-payoff changes in one or two systems. Accomplishing this objective would certainly be a signal achievement to have been set in motion by a workshop, leading to a more survivable UAV system and resulting in better support to the warfighter. Beyond that, it is the belief of the participants that the findings could show

the way to broader future improvements in UAV survivability. As Kevin Crosthwaite, the Workshop Chairman, said, "When the military mind set did not include UAVs, then adding UAVs increased effectiveness and saved lives. Now that UAVs are being integrated into military operations planning, if they are not there (either because of reliability or survivability problems), then their absence hurts effectiveness and could cost other lives." Each UAV



Northrop Grumman's RQ-8A Fire Scout

system should fully consider the prioritized list of survivability enhancements, and the UAV community should embrace the benefits of improved survivability. Future modifications and enhancements for survivability should be planned and programmed along with other system upgrades. New UAV designs should reference this list of cost effective survivability enhancements to ensure that the designs incorporate all that are appropriate to their respective missions. It was our goal to bring the survivability community and UAV community together. The new UAS Roadmap with a new survivability appendix is evidence that this is happening.



A RQ-1 Predator

### About the Authors

Mr. Kevin Crosthwaite is Director of the Survivability/Vulnerability Information Analysis Center (SURVIAC). He has worked on several technical analysis and test programs involving a wide variety of weapons systems. Mr. Crosthwaite has a Masters in nuclear physics from Ohio State and is a licensed professional engineer. He serves on the NDIA Combat Survivability Executive board on the AIAA Survivability Technical

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# Limiting Oxygen Concentrations for Fuel Tank Inerting

■ by Steven M. Summer

Recent advances in technology and in our understanding of fuel flammability and inerting gas requirements have made an Onboard Inert Gas Generation System (OBIGGS) for commercial transport aircraft more feasible, cost effective, and reliable. A major finding leading to this was a shift in the Limiting Oxygen Concentration (LOC); i.e., the oxygen concentration below which ignition of fuel vapors can no longer be supported. The LOC is the main design criterion for any inerting system, because it determines the oxygen levels required to provide adequate protection against fuel tank explosion. Military OBIGGS have been designed to an LOC as low as 9.0% O<sub>2</sub>. However, recent studies at the Federal Aviation Administration (FAA) William J. Hughes Technical Center, combined with a review of previous literature, show that the LOC for aviation grade fuels, such as Jet A, which is used in commercial transport aircraft, can be placed 33.0% higher at 12.0% O<sub>2</sub>. This change in design criteria was instrumental in developing a lightweight, cost effective OBIGGS that safeguards against accidental ignition sources that may occur in a commercial transport aircraft.

## Experimental Apparatus

The experiments were conducted at the FAA Pressure Fire Modeling Facility at the Hughes Center. This unique facility houses a 353 ft<sup>3</sup> vessel capable of withstanding a maximum working pressure of 650 pounds per square inch (psi). A vacuum pump was used to evacuate the chamber to pressures corresponding to those of the desired test altitudes. A vented fuel tank test article, approximately 9.0 ft<sup>3</sup> in volume, was tested inside the pressure vessel.

The test article was equipped with 12 K type thermocouples, sample lines for hydrocarbon and oxygen vapor sampling, thermostatically controlled hot plates, and a mixing fan used to ensure a homogeneous ullage vapor mixture. A fuel pan, measuring 9.5 in x 9.5 in, was placed in the center of the fuel tank. A 10 in x 10 in opening in the fuel tank's roof was fitted with an interchangeable pressure relief mechanism of a spring loaded, 0.25 in thick aluminum plate or an aluminum foil diaphragm.

The aluminum plate mechanism was used in early phases of testing to gain general knowledge of the LOC at each altitude, while the aluminum foil diaphragm was used to more accurately determine the LOC. With the aluminum plate, ignition was said to occur if there was noticeable movement of the plate; with the aluminum foil mechanism, ignition was said to occur only if the aluminum foil diaphragm was ruptured during the test.

Two piezoresistive pressure transducers installed in the tank were also used at oxygen concentrations of approximately 1.0%–1.5% above the LOC at each altitude. These tests, performed to provide more information about the pressure rise associated with these low level oxygen tests, were conducted to increase confidence that any chemical reactions near the LOC would not result in pressure increases that might impact the

structural integrity of the tank. A bank of nitrogen bottles, connected to the fuel tank and controlled by a solenoid valve, served the dual purpose of controlling the ullage oxygen concentration and extinguishing any flames resulting from igniting the ullage vapors.

The twelve thermocouples were used to record liquid fuel, ullage, and tank wall temperatures for monitoring the test. The temperature measurements were also used for fuel vapor modeling work that is currently being undertaken in a joint effort by the FAA and Professor C. E. Polymeropoulos of Rutgers University.<sup>1</sup> A spark/arc gap was placed in the front left corner of the fuel tank. This gap consisted of two 1/16 in diameter tungsten electrodes and was capable of alignment and gap width adjustments. The electrodes were powered by two different spark/arc generators—an arc generating oil burner transformer and a J57 engine spark igniter. A 400 cycle hard short to ground also provided a high powered spark, and a heated surface was used in a few tests involving Hot Surface Vapor Ignition (HSVI). Table 1 shows the measured spark/arc energies for these various ignition sources.

Table 1. Measured spark/arc energies

Ignition Source	Time Duration(s)	Energy (Joules)
Oil Burner Transformer	1.0	0.5
Oil Burner Transformer	0.1	0.08
J 57 Engine Igniter	0.000175	0.5
400 cycle short	0.01	1.8 – 2.8

■ = Thermocouple Feedthrough

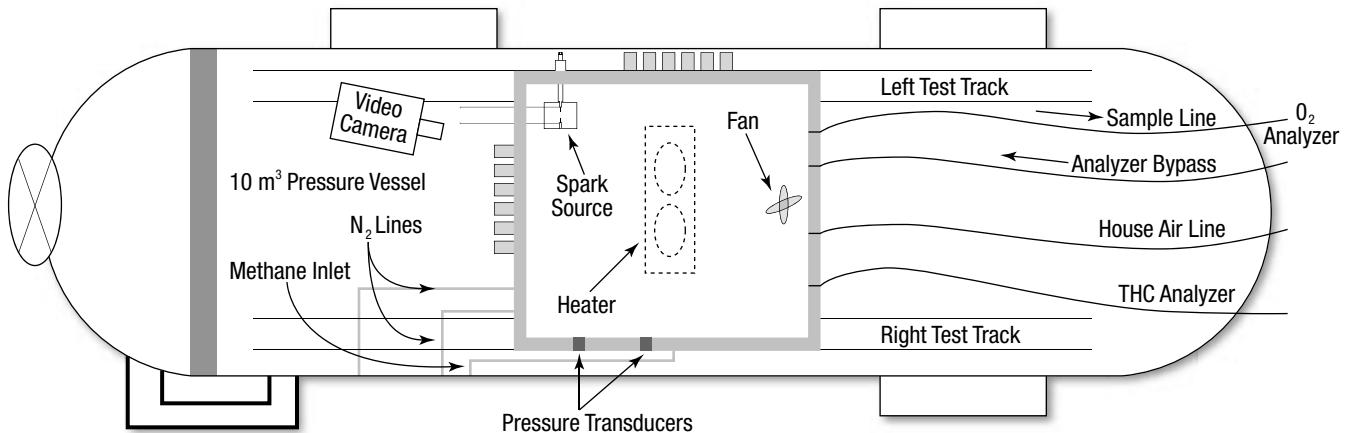


Figure 1. Overall test layout



Figure 2. Pressure vessel

### Experimental Findings

Most tests were conducted with the 1.0 sec duration oil burner transformer arc and the aluminum foil diaphragm for pressure relief. The results from these tests are presented as oxygen concentration against altitude in Figure 4 (see next page), which shows all ignition and non ignition events with the aluminum foil diaphragm pressure relief mechanism, and Figure 5, which shows the minimum O<sub>2</sub> concentration resulting in ignition combined with the maximum O<sub>2</sub> concentration resulting in non ignition at each altitude. From these results, there is a clear indication that the LOC increases with altitude. The LOC rises steadily from an approximate value of 12.0% at sea level and 10,000 ft to approximately 14.5% at 40,000 ft.



Figure 3. Pressure Fire Modeling Facility: the surrounding building and data acquisition trailer

The driving force for the design criteria of an inerting system is the LOC value that occurs at sea level. As such, testing with the other varied ignition sources was conducted only at sea level to determine if these other sources were a higher potential threat than the oil burner arc. These numerous tests showed good agreement with the initial data set, with only one ignition occurring below the previously determined LOC. This ignition occurred at 11.9% O<sub>2</sub> and can easily be attributed to sensitivity errors in the gas monitoring equipment. A more complete discussion of the data compiled with these other ignition sources can be found in online at [www.fire.tc.faa.gov/pdf/04\\_8.pdf](http://www.fire.tc.faa.gov/pdf/04_8.pdf).<sup>2</sup>

Although the military used a design requirement as low as 9.0% O<sub>2</sub> for their inerting systems, the sea level LOC data are consistent with previous data, as shown in Zinn's extensive literature search in 1971.<sup>3</sup> Zinn found that the resulting LOC, determined by various experimental studies, varied approximately 1.0%, falling in the 11.5%–12.0% O<sub>2</sub> range. A review of the literature shows that the military aircraft inerting system design criteria of 9.0% is a result of a US Bureau of Mines recommendation to use a 20% safety margin.<sup>4</sup>

Currently, commercial aircraft inerting systems are being designed to protect against potential, accidental ignition sources that exist within the fuel tank itself. It may well be that since the military faces more severe threats, their design requirements should be more stringent than those of the commercial fleet. For instance, an incendiary projectile entering a fuel tank can cause air entrainment and enhanced mixing of the fuel vapor, thus creating a more volatile region in the ullage space.

While there is scarce published data available for the LOC at altitude, Stewart and Starkman<sup>5</sup> did perform some altitude work with both carbon dioxide and nitrogen inerting. Their data, however, was generated by using flame propagation as the ignition and non ignition criteria, with a visible flame front considered as an ignition. The resulting pressure rise was not used as a criterion, and it is noted in their report that, at times, flame propagation occurred with little or no resulting pressure rise. Because of this difference in criterion, the Stewart and Starkman data set tends to be lower than the data generated here, starting at approximately 9.8% O<sub>2</sub> at sea level and increasing to approximately 10.8% at 30,000 ft and 13.0% at 60,000 ft. While the disparity in criteria does not permit direct comparison of the Stewart and Starkman data to the data presented in this article, it does verify the trend of decreasing inerting level requirements (higher LOC) as altitude is increased.

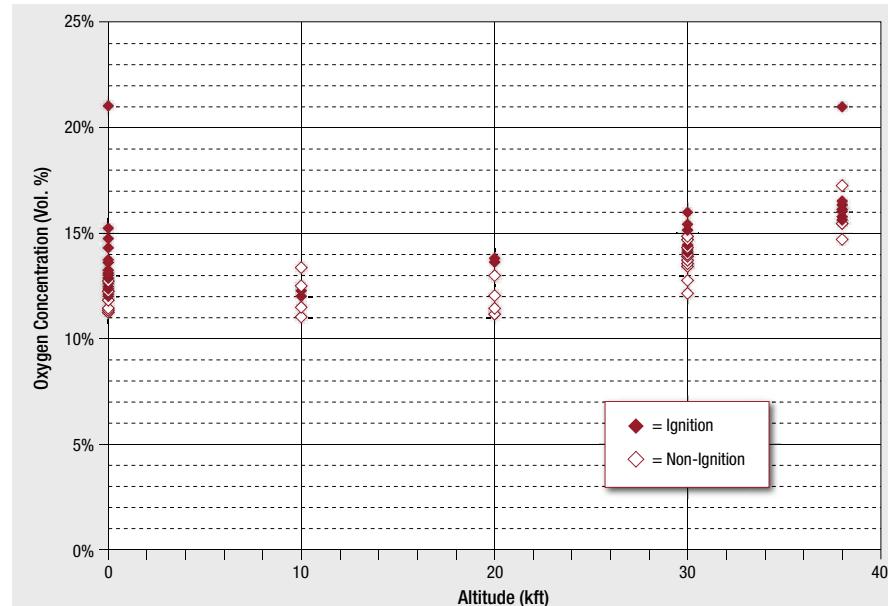


Figure 4. All ignition and non ignition events with the aluminum foil diaphragm pressure relief mechanism

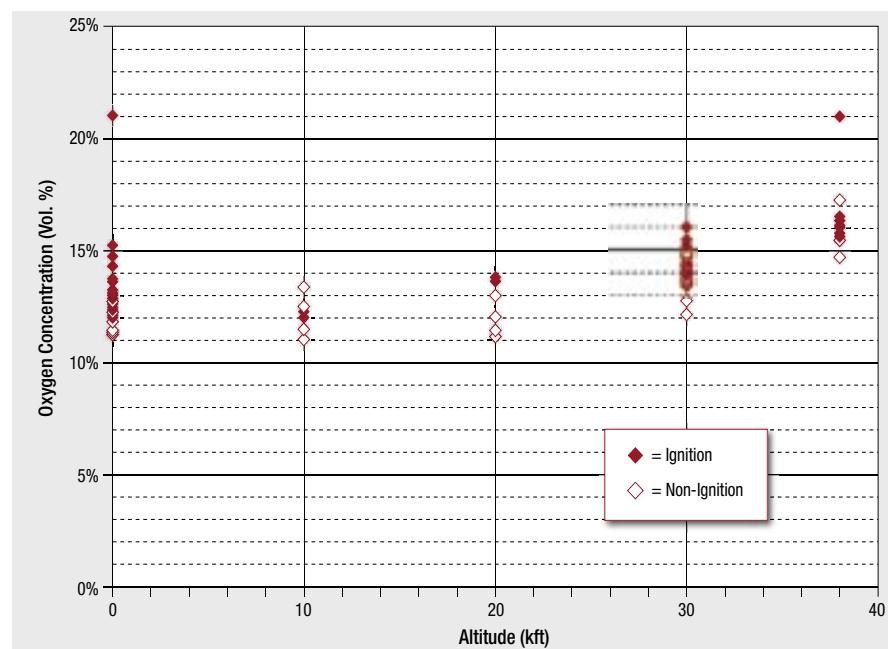


Figure 5. Minimum O<sub>2</sub> concentration resulting in ignition combined with the maximum O<sub>2</sub> concentration resulting in non ignition at each altitude

When the LOC tests were completed, tests were conducted to measure pressure rises caused by ignition at low oxygen concentrations and to examine the effect of increasing altitude from 0.0 ft—30,000 ft, with the aluminum foil diaphragm acting as the pressure relief mechanism. Testing was limited to oxygen levels of approximately 1.0%–1.5% above the LOC values previously determined. (See Figure 4.)

Both transducers recorded similar values, and the averaged results are shown in Figures 6 and 7 (see next page). As shown in Figure 6, a decrease in peak pressure is observed as altitude is increased from zero to 30,000 ft. Figure 7 shows that the time duration to reach the peak pressure increases as altitude is increased.

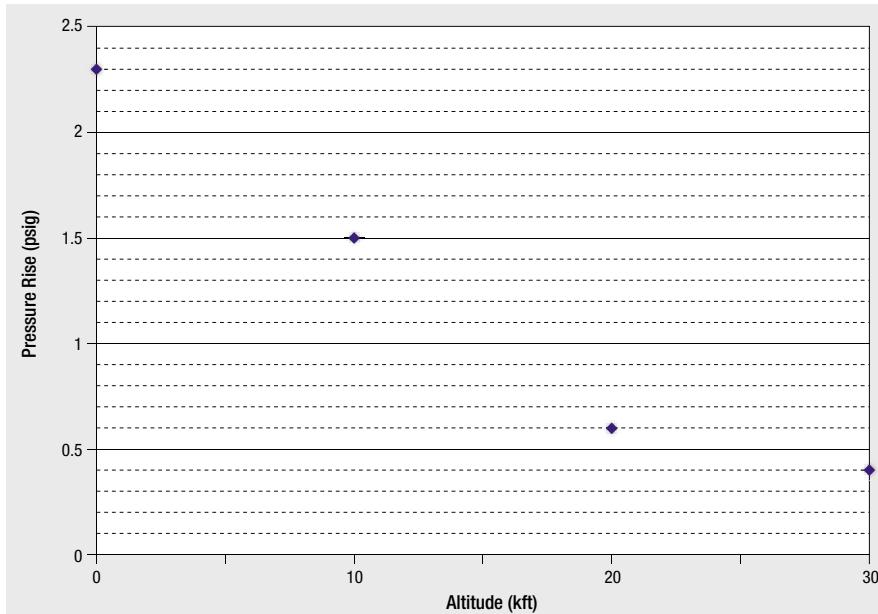


Figure 6. Peak Pressure Rise at O<sub>2</sub> Concentrations 1%–1.5% Above the LOC

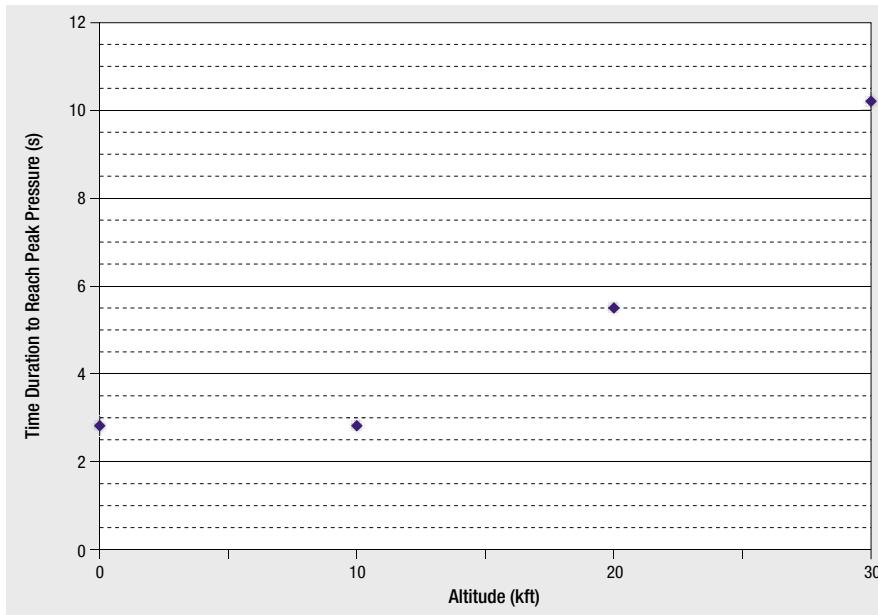


Figure 7. Time duration to reach peak pressure

It should be noted, however, that after the aluminum foil diaphragm ruptured, the transducers were reading the entire chamber pressure. For this reason, the peak pressures recorded in Figure 6 seem relatively small, and, similarly, that time durations in Figure 7 are relatively long. Since the vessel volume is approximately 40 times that of the volume of the fuel tank, peak pressures shown in Figure 6 are approximately 1/40th of the potential pressure rise that occurs in a closed, non vented environment. This appears to be consistent with Shepherd, et al.,<sup>6</sup> in which the investigators recorded pressure rises near 50 pounds per square inch gauge (psig) at pressures equivalent to an altitude of approximately 15,000 ft.

The pressure rise data was substantiated by a few experiments within the full pressure vessel with no post ignition pressure relief. In these tests, a 3.0 ft x 6.0 ft fuel pan was placed inside the vessel, with the equivalent fuel loading as in previous tests, and heated by three of the identical hot plates used in the 9.0 ft<sup>3</sup> tank, which were attached to the bottom of the pan. Ignition was achieved using the same transformer, connected to two 1/8 in steel electrodes. Vessel pressure was recorded by a 0.0 psi–200 psi, sealed gauge, diaphragm type transducer. Because of the increased condensation effects within this chamber, tests were restricted to altitudes above 20,000 ft. The results of these tests are shown in Table 2.

When extrapolating the results in Figure 6 to provide a data point of approximate-

Table 2. Non vented, full vessel, ignition pressure results

Altitude (thousand ft)	Oxygen Concentration	Initial Pressure pounds/square inch absolute (psia)	Final Pressure (psia)	Differential Pressure (psia)	Differential/Initial Pressure
20	21.0%	6.9	33.7	26.8	3.88
20	15.0%	6.8	30.5	23.7	3.49
38	21.0%	3.5	16.1	12.6	3.60
38	17.3%	3.8	16.5	12.7	3.34

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# Addressing Maritime Patrol Aircraft Survivability

■ by Dave Legg and Joseph Landfield

To the casual observer, Boeing's solution to the US Navy's need for a next generation Maritime Patrol Aircraft (MPA) looks like a 737 airliner painted a lackluster gray. But the Boeing concept being developed under a \$3.89B System Development and Demonstration (SDD) contract entails many design modifications to the popular commercial jet that will transform it into a highly capable, versatile, lethal and survivable guardian of the seas. The 737 Multi-mission Maritime Aircraft (MMA) shown in Figure 1 is the latest instance in a long and successful history of adapting passenger aircraft to the MPA role. Heritage designs, such as the Navy's P-3C Orion and the Royal Air Force's MR2 Nimrod, were originally derived from the 1950s-era Lockheed Electra and De Havilland Comet, respectively. They proved to be rugged, effective platforms throughout the Cold War and beyond, notably during the ongoing conflicts in Southeast Europe and Southwest Asia. By employing good system engineering practices in the early stages of development, MPA derived from commercial airliners can provide impressive levels of combat survivability while remaining highly cost competitive. The 737 MMA currently being designed is expected to have survivability characteristics that not only improve on the P-3C that it replaces but may actually exceed nominal levels for contemporary military airlifters.

## MPA Survivability Evolution

The evolution from a flying prototype based on the L-188 Electra, shown in Figure 2, to the latest model of the P-3C Orion has taken more than 30 years. The initial P-3A had little in the way of survivability features other than an inherently rugged airframe design. The lack of emphasis on survivability reflected its intended Cold War role of open-ocean,

anti-submarine warfare. However, not too long after its entry into service, the P-3's roles and missions began to expand to include more threat environments. For example, in 1968, during the Vietnam War, P-3 aircraft supported Operation Market Time by identifying and tracking various trawlers and junks that were suspected of delivering supplies to the enemy. Such missions were conducted at altitudes of 1,000 ft or below and within 20 miles of the Cambodian coastline. Although official details are sketchy, one P-3 aircraft assigned to VP-26 was lost to an engine or wing dry-bay fire after being shot at by a machine gun on board a landing craft. Curiously, two months ear-

significant survivability gains could be achieved by incorporating fuel tank ullage explosion suppression, dry-bay fire detection and suppression, missile threat warning, a radio-frequency (RF) jammer and/or decoys, and infrared (IR) jammers and/or countermeasure flares. A limited number of P-3C aircraft were subsequently modified by installing two ALQ-157 IR jammers, reticulated foam in the wing fuel tanks, and a tactical paint scheme.

In 1987, the Navy issued a Request For Proposal (RFP) for a P-3 replacement: the Long Range Air Anti-submarine Capable Aircraft (LRAACA). The RFP contained detailed specifications that were drawn from results of the P-3 survivability studies conducted earlier that decade. The RFP responses included two commercial derivative aircraft (Boeing 757 and McDonnell Douglas MD-80) and a Lockheed offering with lineage to the P-3 and L-188 designs. Lockheed's winning P-7 concept incorporated all the features recommended earlier for the P-3, such as measures for addressing fuel tank ullage and dry-bay vulnerabilities and an integrated IR and RF self protection suite comprising six ALE-47 chaff and flare dispensers, four AAR-47 missile approach warning sensors, an ALE-50 towed decoy system, and radar warning by an ALR-66 system. IR signature reduction was also part of the proposed P-7 concept.

Unfortunately, the P-7 design never left the drawing board—the LRAACA program was terminated in 1990. However, the ensuing Anti-surface Warfare Improvement Program (AIP) did eventually lead to updating P-3Cs with an IR countermeasure suite (six ALE-47 dispensers and four AAR-47 sensors), wing tank foam, and a reduced vis-



Figure 1. Navy/Boeing 737 Multi-mission Maritime Aircraft

lier, another P-3 from VP-26 had crashed into the same waters after reporting a suspicious contact. In this case, aircraft wreckage was located, but the cause of the crash was never determined.

Other than occasional tasking such as Operation Market Time, the P-3 fleet remained devoted to regular open-ocean monitoring of Soviet naval assets throughout the 1960s and 1970s, the type of missions that typified the Cold War. An ever-increasing surveillance role for the P-3 in the Persian Gulf region led the Navy to take a closer look at the changing threat, and, in the early 1980s, several P-3 studies in improving survivability were commissioned. The studies found that operationally

ibility paint scheme. Sixty four P-3C AIP aircraft are currently in the MPA force, with eight more scheduled for this upgrade. Today, these P-3C AIPs serve on the front lines, continually in demand to support coalition forces in the Global War on Terrorism.

Like its transatlantic ally, Great Britain has, over the years, seen an expansion of missions for its MPA fleet of Nimrods. Derived from the civilian DH-106 Comet 4C airliner, the Royal Air Force (RAF) Nimrod entered service in 1969 as the MR1 version, having been primarily designed for anti submarine and anti surface vessel warfare in "blue water" (i.e., deep water and open ocean), much as was the P-3 Orion. The Nimrod's primary sub surface and surface surveillance sensors were upgraded to the MR2 standard beginning in 1975. Lessons learned from conducting combat search and rescue operations in the 1982 Falklands War sparked the initial consideration of enhancing MPA survivability, especially as the Nimrod's operational areas of responsibility entailed more "brown water" (shallow coastal water) environments. In preparation for the Gulf War (Operation Granby), RAF MR2 Nimrods were fitted with towed radar decoys, missile approach warning sensors, and chaff and flare dispensers.<sup>1</sup> The RAF is currently undertaking a major modification program of the MR2 Nimrod inventory to meet the Maritime, Reconnaissance, and Attack (MRA4) standard. Further survivability improvements will be provided by a comprehensive self protection suite, integrated through the Defensive Aids Subsystem (DASS), consisting of upgraded radar warning, missile approach warning, towed radar decoy, and an expendables dispenser system.<sup>2</sup>

## Navy MPA Replacement Program

In the late 1990s, it became clear to the Navy's leadership that inventory P-3C airframes were rapidly reaching the end of their useful life and were in need of replacement. An Initial Operational Capability (IOC) date for the P-3

replacement was scheduled for no later than 2015, but this target was later accelerated by the Secretary of the Navy to the 2012 time period. In February 2000, the Joint Requirements Oversight Council (JROC) validated the core warfighting requirement for MMA, as summarized in the Broad Area Maritime and Littoral, Armed Intelligence, Surveillance, and Reconnaissance (ISR) Mission Need Statement (MNS), and a few weeks later, the Defense Acquisition Board (DAB) approved the start of MMA Concept Exploration (CE).

The MMA CE phase effort was directed toward identifying and evaluating promising system concepts. Sponsored activities included an Analysis of Alternatives (AoA) led by the Center for Naval Analyses in Arlington, VA, and four study contracts with industry: Lockheed Martin and Raytheon, who both examined P-3 re manufacture approaches; Boeing, who

the Nimrod MRA4, European Aeronautic Defence and Space Company (EADS) for an Airbus A320 commercial aircraft derivative, and General Dynamics for a Gulfstream 550 business jet derivative. In system performance and overall cost of ownership, the CE phase found that no clearly dominant alternative was evident among the medium sized, commercial derivative jets and the concepts derived from the Orion or Nimrod. All these options were deemed to have the potential capabilities necessary for the Navy's 21st century MPA, assuming that substantial investments are made up front for developing a robust air vehicle and for integrating an effective and adaptable mission equipment suite.

The MPA replacement program proceeded to the next stage of pre development following a formal review by the Navy and the US Department of Defense in January 2002. The purpose of the MMA Component Advanced Development (CAD) phase was to define a total system architecture for each alternative concept, identify and mitigate associated risk areas, determine total life cycle costs, and continue the iterative process of refining operational and system level requirements that began in 1998. To more fully develop their respective MMA concepts, 19 month CAD contracts were awarded to Boeing and Lockheed Martin, thereby reducing technical and programmatic risks in anticipation of an eventual full scale development activity. BAE Systems initially participated in the CAD competition with a version of the Nimrod MRA4; however, the company withdrew its proposal before the contract was awarded.



Figure 2. YP3V-1 Prototype Modified from L-188 Electra (above) and Royal Norwegian Air Force P-3C Orion (below)

assessed the application of a 737 commercial aircraft derivative; and Northrop Grumman, who investigated the potential utility of the RQ-4 Global Hawk Unmanned Aerial Vehicle (UAV) as an adjunct to a manned MPA. Additional responses to requests for information were also received from BAE Systems for

On May 28, 2004, the DAB authorized the MMA program's entry into System Development and Demonstration (SDD). Two weeks later, Boeing was selected as the MMA prime contractor over Lockheed Martin's proposed Orion 21 concept, a modernized version of the P-3. Boeing's proposed MMA design is a derivative of the 737-800, with extensive modifications for mission avionics, weaponization, and higher gross weight

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# Kelly J. Kennedy

## Excellence in Survivability

■ by Dale B. Atkinson

**T**he Joint Aircraft Survivability Program Office (JASPO) is pleased to recognize Kelly J. Kennedy for Excellence in Survivability. Kelly is the group leader for Vulnerability Analysis and Live Fire Test and Evaluation (LFT&E) in the Operational Analysis Branch of the Aeronautical Systems Center's Design, Analysis, and Simulation Division (ASC/ENMM), Wright Patterson Air Force Base (AFB), OH.

Kelly graduated cum laude from the University of Akron in 1983 with a BS in Mechanical Engineering. He received an MBA with honors from the University of Cincinnati in 2004 as a member of the first class of the Aeronautical Systems Center's on base mid day MBA program. He has been a registered Professional Engineer (PE) in Ohio since 1989.

Kelly began his career at Wright Patterson AFB as a structural analyst with the 4950th Test Wing's Aircraft Modification Center, which was an organic Air Force organization that modified aircraft for development flight testing purposes. Most projects were designed, analyzed, fabricated, installed, and flight tested by in house personnel. Kelly gained expertise in both hand and computer analyses on many unique or limited production Research & Development (R&D) efforts. He is experienced in aircraft structural capabilities, loads, fatigue concepts, material properties, and the overall process for both internal and external aircraft modifications. His diverse job also had him working with gears and mechanisms, ground support equipment, structural tests (both at the component and system level), and liaison work (including Material Review Board actions) with fabrication and installation personnel. Kelly obtained unique, hands on, engineering design experience during his more than 13 years in the Test Wing.

During this time he was lead engineer on a number of aircraft modification programs, including the T-38 HUD and the Open Skies Camera Systems Group. He also worked several mechanical systems projects, such as the KC-10 On-Board Loader and a two axis rotating mechanism for 30,000 lb class signature models for the RATSCAT Advanced Measurements (RAMS) facility at Holloman Air Force Base. He was also the sole engineering representative on a four man Air Force Systems Command/Air Force Logistics Command (AFSC/AFLC) Independent Review

Team on the 60K Loader program at Warner Robins Air Logistics Center (ALC) to assess government contractor disputes, the engineering portion being the major area of cost in question. Several years later he was selected as a member of an Executive Independent Review Team on the same program.

In 1997, Kelly moved to ASC's Engineering Directorate where he used his engineering stress analysis skills to develop a methodology to build and verify computer models of SHAZAM endgame targets. He has used this process to build pedigreed databases for the entire Air Force inventory of fighters and bombers and for many other specialized hit to kill models. This is the only complete set of Air Force hit to kill databases, which are widely used throughout government and industry and distributed with the ASC versions of the Enhanced Surface To Air Missile Simulation (ESAMS), as well as through other forums.

As Kelly developed his expertise in vulnerability analysis, he was assigned to the position of model manager for several vulnerability and endgame models—Fast Target Generation Model (FASTGEN), Computation of Vulnerable Areas and Repair Times (COVART), and SHAZAM. Kelly initiated several model and process improvements that supported government and industry analysts. He also supported the development of Pedigree threat characterization databases for both gun and missile systems threats, which are the standard used for vulnerability and endgame analyses by many agencies in both industry and government. These databases are critical to vulnerability analysts and provide a means for more consistent and credible analyses. As part of the Pedigree verification process, he applied a graphical methodology to properly convert ammunition polar zone test data to a format usable for Modeling, Simulation & Analysis (MS&A).

Kelly supported the F-35 requirements development activities. He was the lead engineer on the F-16C vulnerability assessment, which provides the baseline for F-35 specification. Kelly managed and supported the development of the vulnerability databases and the conduct of the system analysis. He also was a Vulnerability Assessment Panel voting member on the very important Directed Energy Applications in Tactical Aircraft Combat (DEATAC) study.

Based on his previous experience in developing endgame and Pedigree databases, Kelly worked with the Missile and Space Intelligence Center (MSIC) in Huntsville, AL, and the 547th Intelligence Squadron at Nellis AFB, Indian Springs, NV, on modeling threat lethality to develop a realistic warhead lethal radius methodology. Through a series of informational briefings, Kelly recommended updates to the Air Force Tactics, Techniques, and Procedures Manual 3-1 (AFTTP3-1). AFTTP3-1 is used by aircrews worldwide and is recognized as the authoritative source for data on threat capabilities and on aircraft system operation in combat situations. He has also been involved in several other endgame initiatives, including post combat incident assessments and support to the Joint Combat Assessment Team (JCAT), currently based in ASC/ENMM, which is sponsored by the JASPO. The JCAT is collecting combat data in Iraq and other combat zones, and Kelly has conducted endgame assessments based on JCAT post combat incident data. These assessments are leading to a new Combat Damage Assessment Tool, funded by JASPO, which he is managing. This tool is intended to be used in the field to aid the JCAT to conduct assessments with increased speed and likelihood of yielding correct analyses. Rapid analysis of potential engagement conditions will allow commanders to better understand the threat environment and alter tactics to protect lives and assets.

Kelly is the technical lead for the ongoing C-5 Live Fire Test & Evaluation (LFT&E) program, where he guides the technical activities to ensure that products meet program office requirements as defined within the Test and Evaluation Master Plan (TEMP). Kelly's leadership of the C-5 LFT&E program has resulted in significant evaluation improvements. This program was the first at the Guided Weapons Evaluation Facility (GWEF) at Eglin AFB, FL, to attempt to predict accurate Man Portable Air Defense Systems (MANPADS) impact points on an aircraft in their hardware in the loop simulation facility. The Office of the Secretary of Defense (OSD)/LFT&E Action Officer for this program said "The C-5 Reliability Enhancement and Re Engineering (RERP) LFT&E Program should be documented as a Defense Systems Management College (DSMC) case study" for the management, innovation, and technical rigor under which the program is executed. Kelly also has been involved in the F/A-22, B-1B, Personnel Recovery Vehicle, and other LFT&E programs.

Kelly is also the Chairman of JASPO's Vulnerability Methodology Committee, and he and his team manage many projects funded by the JASPO and System Program Offices (SPOs), including methodology and database developments, program technical support, and analyses. He is currently managing a project, funded by JASPO, to update two volumes of the Pedigree Threat Database for gun and missile threats. Another recent project he is managing is the Fire Prediction Model (FPM) Emergency Repairs, which is an effort to correct obvious error drivers so as to allow the code to be used with confidence for the Joint Strike Fighter (JSF) and other programs.



Kelly and his wife, Vickie, live in Vandalia, OH, with their five children: Jesse, Jonathan, Amy, Daniel, and Elaina. When he has time, he likes to spend some of it outdoors. He enjoys guns and cartridge reloading and likes wilderness experiences, such as hunting, hiking in less traveled areas, salt water fishing, or an occasional white water rafting trip. Earlier in life, he had taken varied routes, such as being a certified life guard, getting a varsity letter in high school diving, earning a brown belt in college Tae kwon do, and enjoying rock climbing.

It is with great pleasure that the JASPO honors Kelly Kennedy for his Excellence in Survivability contributions to the JASPO, the survivability discipline, and the warfighter.

### About the Author

Mr. Dale Atkinson is a consultant on the aircraft combat survivability area. He retired from the Office of Secretary of Defense in 1992 after 34 years of government service and remains active in the survivability community. Mr. Atkinson played a major role in establishing survivability as a design discipline and was a charter member of the original tri-service JTCG/AS, now called the JASPO. He was also one of the founders of the DoD sponsored SURVIAC. He may be reached at [jasnewsletter@jcs.mil](mailto:jasnewsletter@jcs.mil).

## Continued from Page 15

operations in projected maritime and littoral mission environments. The first capability increment of MMA will be fielded no later than 2013.

The MMA program's acquisition strategy mandates timely future increments of enhanced system capability using a spiral development process that will keep pace with emerging threats and joint warfare concepts of operation. The approach to time phased improvements will leverage the baseline MMA's air vehicle design and its modern, open system architecture to focus resources on integrating advanced mission system technologies with a minimum of hardware and software redesign. Currently, a large initial investment in the 737 MMA platform and avionics infrastructure is being made to enable system growth and flexibility through each future spiral.

## MMA System Requirements

MMA responds to the Navy's 21st century need for a long range aircraft capable of conducting the primary missions of armed Anti-submarine Warfare (ASW), armed Anti-surface Warfare (ASuW) (i.e., anti-ship), Intelligence (INT), Command, Control and Communications (C3), Command and Control Warfare (C2W), Mine Warfare (MIW) and Mobility (MOB). MMA is expected to operate in both littoral environments and blue-water seas, covering operations that range from peacetime engagement through conventional, high intensity, regional warfare. In many situations, MMA will be the first or only force asset in area and the only reliable US source of information, thus making it the sole provider of a comprehensive, wide-area, tactical picture that will be injected into the Global Information Grid (GIG) using the Navy's FORCEnet implementation. MMA will be capable of sustained, independent operations when forward deployed to non-US airfields. Projected threats facing MMA will be a combination of many diverse systems, with the degree of severity depending on mission scenarios.

Three iterations of the MMA Initial Requirements Document (IRD) were completed during the CE and CAD phases by using a refinement process that included recurrent feedback from P-3C fleet users and operational commanders, plus a series of cost benefit analyses by the Navy/Industry team. This three-year effort produced an Operational Requirements Document (ORD) validated and approved by the JROC on December 8, 2003, in preparation for the Milestone B DAB Review and award of the SDD contract.

Under the CAD contracts, Boeing and Lockheed Martin conducted numerous trade studies related to survivability that covered various means of reducing susceptibility (by threat warning and countermeasures for IR, radar, and other spectra) and vulnerability (by dry-bay fire detection and suppression and fuel tank ullage explosion suppression). The MMA Program Office also sponsored a cooperative series of survivability studies involving the Naval Air Warfare Centers at Patuxent River, MD, and China Lake, CA; the Naval Surface Warfare Center at Crane, IN; and the Johns Hopkins University Applied Physics Laboratory.<sup>3</sup> Figure 3 presents the results of a key MMA trade study for achieving a cost-effective survivability solution from a total system perspective. The findings of these important studies were critical to defining a balanced set of survivability

requirements in the MMA ORD and the MMA Performance Based System Specification (PBSS).

For operational missions in projected threat environments, the MMA ORD and PBSS call for an affordable mix of survivability features that includes situational awareness, integrated threat warning and electronic countermeasures, signature suppression, and combat damage tolerance. Boeing's winning proposal met the Navy's performance-based requirements by equipping the 737 MMA with a survivability suite that includes an On-board Inert Gas Generating System (OBIGGS) to suppress fuel tank ullage explosions induced by ballistic threat; Chemically Active Gas Generators (CAGGs) to suppress dry-bay fires induced by ballistic threat; a significant amount of critical flight controls redundancy with separation (inherited from its commercial design ancestry); missile and radar warning systems for threat avoidance and countermeasures employment; countermeasure dispensers; a Directed Infrared Countermeasure (DIRCM) system for susceptibility reduction to IR-guided surface-to-air missiles (SAMs); and Radio Frequency Countermeasure (RFCM) provisions for susceptibility reduction to RF-guided SAMs. Figure 4 illustrates the overall arrangement of the 737 MMA survivability subsystems. The 737 MMA also incorporates a modern Electronic Support Measures (ESM)

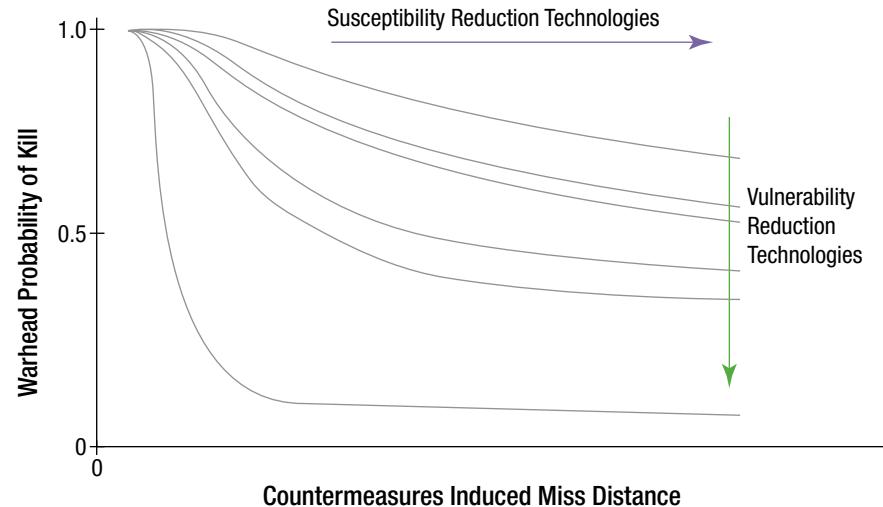


Figure 3. Survivability enhancement synergies

system that contributes to an aircrew's situational awareness of threat emitters. When fielded in 2013, the 737 MMA is expected to have mission survivability levels on a par with or better than contemporary military airlifters or other large, airborne ISR platforms.

The Navy/Industry team continues to work closely with the Office of the Secretary of Defense (OSD) in establishing MMA Live Fire Test & Evaluation (LFT&E) requirements. The Director of Operational Test & Evaluation (DOT&E) designated the MMA as an LFT&E oversight system and indicated his support for a waiver from Congressionally mandated Full-up System Level (FUSL) testing, if the Navy showed in this case that FUSL testing was not cost effective. The Alternative LFT&E Test Plan/Strategy for MMA, which received approval in 2003, will be implemented as an integral part of the MMA design process to reduce vulnerability and enhance survivability. The plan will make appropriate use of Modeling and Simulation (M&S), existing damage incident data, and testing of flight critical subsystems, sub assemblies and/or simulators and surrogates to specifically address the critical LFT&E issues before proceeding with MMA full rate production.

### The Road Ahead

Transformation of the Navy's MPA community is well under way with the development of the 737 MMA and the continuing modernization of the P-3C weapon system. The forward-deployed MPA force provides a substantial contribution to the projection of Joint and Allied combat power by ensuring rapid and sustained access into any region of the world. Over the next few decades, adversaries seeking to expand their regional influence will create greater challenges to this access. Because MPA assets are very often some of the first to arrive in theater, their ability to conduct missions in potentially hostile environments is critical to the national military strategy for overlapping campaigns and for multiple, lesser contingencies.

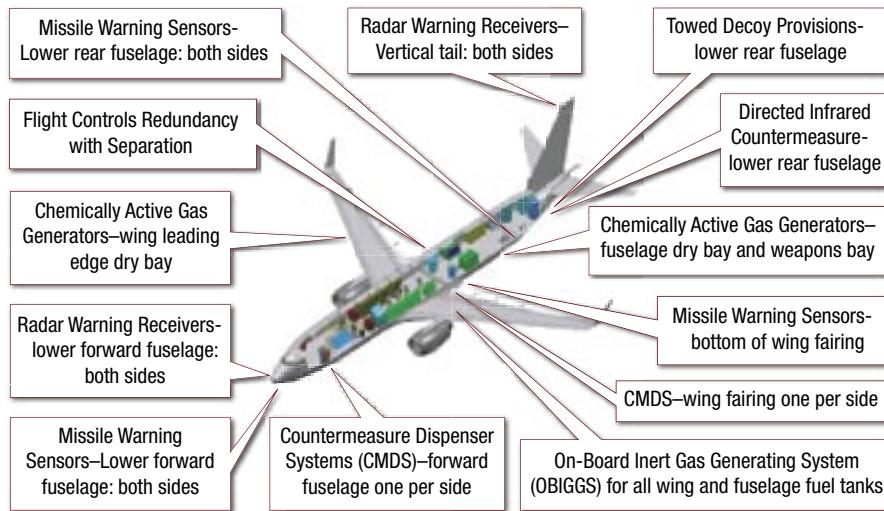


Figure 4. 737 MMA Survivability features.

Pacing the threat is a basic objective of the MMA program roadmap, and the use of an evolutionary acquisition strategy coupled with a modern, open system architecture will facilitate any need to further enhance 737 MMA survivability. In coming years, potential threats may be characterized as technological evolutions of current systems, or they may entail unconventional concepts involving asymmetric warfare targeted at information systems or kinematic weapons launched from space or under the sea. MMA may address far-term threats by capitalizing on advancements in network-centric warfare and the common operational picture and by employing new operational concepts involving MMA and adjunct UAVs. Analytical assessments of advanced technologies and systems by the Navy and Boeing team will also be an ongoing effort to satisfy emerging requirements with solutions that offer improvements to cost, weight, and program risk.

The uppermost goal that guides the 737 MMA program's baseline system design and later spiral developments is to provide the MPA fleet commander an aircraft that is continually effective and suitable for its intended missions in maritime and littoral environments. Building on the experience of MPA operations in the post-Cold War era, the 737 MMA will bring to bear a broad array of technologies for protecting an aircraft and its crew to maximize the likelihood

of mission completion—which goes well beyond painting the world's most prevalent passenger jet a lackluster gray.

### About the Authors

Dave Legg is the MMA Survivability Lead for Naval Air Systems Command, Patuxent River, MD. He has contributed to many previous aircraft development activities, including the P-7 LRAACA program, the AX, A-12, Naval Advanced Tactical Fighter, F/A-18, V-22, and BQM-145 Medium Range UAV.

Joseph Landfield is the MMA Advanced Development Director for Naval Air Systems Command, Patuxent River, MD. He has been involved with MMA since its inception, directing the technical effort during the CE phase and leading overall efforts in requirements generation and cost benefit trade-offs during the CAD phase. His aircraft development experience includes 20 years at Lockheed and Northrop Grumman on such programs as the F/A-22, X-29, and F-14.

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## Joint Live Fire/Aircraft Systems Program (JLF/Air)

■ by Jeff Wuich and John Murphy

From 1963 to 1973, US military services lost approximately 5,000 aircraft to enemy fire in Southeast Asia (SEA), with losses equally divided between fixed wing aircraft and rotorcraft. From the late 1970s to the present, a total of 168 incidents of damage to large aircraft have been recorded as a result of combat or terrorist action, with the severity of the damage ranging from very light (small arms rounds piercing an aircraft without impacting any components) to complete loss of an aircraft. In recent years, the US military has purchased fewer and more expensive weapon systems and has extended the life of fielded weapons systems beyond their intended life spans. Combining this with the ever changing missions and threats that our aircraft encounter highlights the significant increase in the importance of surviv-

ability in the design of military aircraft—fighters, heavies, rotary wing, Unmanned Aerial Vehicles (UAVs), etc. Simply put, attrition rates such as those experienced in SEA are unacceptable today.

The first step in addressing aircraft survivability is to assess when an aircraft is susceptible to a hit and by what threat(s). Aircraft are most susceptible to threats during takeoff and landing when they are relatively slow and low to the ground. Damage sustained by C-130s used in Operation Just Cause and Kosovo were created from small arms and automatic weapons, with the majority of impacts to the sides and lower half of the aircraft. This type of damage could occur for any aircraft during the takeoff and landing phases of its mission, depending on perimeter security. Another threat during

takeoff and landing is the Man Portable Air Defense System (MANPADS), as evidenced by the DHL airliner, C-5, and C-17 incidents in Baghdad, Iraq. Threats are present during each phase of a mission. For example, on March 24, 2003, during Operation Iraqi Freedom, 33 Apache rotorcraft were ordered to fly ahead of the Army's 3rd Infantry Division to attack an Iraqi Republican Guard regiment in the suburbs of Karbala. Small arms and shoulder mounted, rocket propelled grenades hit 30 of these rotorcraft; one Apache was shot down and two crew members were taken prisoner. Air to air and surface to air missiles are yet another concern. Missiles exist that are guided by radio frequency (RF), infrared (IR), and Anti Radiation Missiles (ARM) and can attack from short, medium, and long range. Vulnerability to any of these threats may include a combination



Figure 1. CH-53E Test Setup at China Lake, CA

of engine and/or fuel tank fire, internal explosion, structural airframe damage, or aircrew injury. Aircraft can sustain any level of kill, from immediate kill to loss of ability to accomplish its mission because of damage inflicted on mission critical equipment. Even aircraft as stealthy as the F-117 are susceptible to a hit, as evidenced by the downed F-117 over Kosovo on March 27, 1999.

The second step in addressing aircraft survivability is to understand how these threats affect an aircraft when all countermeasures fail and the aircraft is hit. To assess the overall survivability of an aircraft, it is important to understand the tools, methodologies, and test series used to assess aircraft susceptibility and vulnerability. These tools include target description(s), flight path generation models, missile engagement [RF or Electro Optical/Infrared (EO/IR)] models, SA/AW and AAA engagements, missile end game, computation of vulnerable area and repair times, fire and explosion predictions, component damage, and kill values. Computer models are used to identify vulnerable areas of a specific aircraft to specified threats. Once the vulnerable areas are identified, a level of confidence is associated with these values. Any values that have a low to medium confidence level can be candidates for live fire tests. However, combat data or data from previously completed Joint Live Fire (JLF) Projects and Live Fire Test & Evaluation (LFT&E) Programs can be used to help address the low to medium confidence levels.

The Joint Live Fire (JLF) Program was initiated by the Office of the Secretary of



Figure 2. RPG Test at Aberdeen Proving Ground, MD

Defense (OSD) in March 1984 to establish a formal process to test and evaluate fielded US systems against realistic threats. Its primary objectives are to assess the vulnerability of fielded US armored vehicles, ships, and military aircraft to threats likely to be encountered in combat and to evaluate the lethality of fielded US munitions against realistic targets. The program continues today under the auspices of the Deputy Director, Operational Test and Evaluation/Live Fire Test and Evaluation (DDOT&E/LFT&E).

JLF/Air FY05 projects will provide empirical data on currently fielded US aircraft to obtain a better understanding of their vulnerability and to identify ways to reduce it. These efforts will aid in planning combat missions, increasing aircraft and aircrew combat survival and effectiveness, providing battle damage assessment repair training, and providing design recommendations to reduce the ballistic vulnerability of current and future US aircraft. This valuable information is made available to the test and evaluation community, system program offices, and the warfighter. The FY05 JLF/Air Program consists of vulnerability tests and assessments on the following rotorcraft and fixed wing aircraft: AH-1, AH-64, CH-47D, CH-53E, OH-58D, UH-60, A-10, and the Predator UAV. Large turbofan engine and control surface vulnerability to the MANPADS threat were initiated in FY04 and FY05, respectively. A tri service effort to obtain a basic understanding of rotorcraft vulnerability to rocket propelled grenades was completed in FY05. JLF/Air FY05 projects support the following focus areas:

### Warfighter Needs

Working with the Joint Combat Assessment Team (JCAT), User Commands, and Program Offices to address Warfighter needs. These projects will be used to obtain an understanding of the types of combat damage experienced from Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) in Afghanistan, how serious the damages are, and whether any "quick

fixes" exist. If there are no quick fixes, the solution may be to alter tactics, techniques, and procedures to limit exposure time to the threat(s).

■ **OH-58D Kiowa Warrior**—In FY05, three OH-58D Kiowa Warrior efforts were funded under JLF/Air to address damage incurred in OIF and OEF: Cockpit Aircrew Ballistic Vulnerability, Fuel Subsystem Ballistic Vulnerability, and Rotor Control Subsystem Ballistic Vulnerability.

● **Cockpit Aircrew Ballistic Vulnerability**—Plan and conduct gunfire tests against components of the OH-58D cockpit to obtain a basic understanding of the potential for system kills and aircrew injury. Testing will take place in the second quarter of FY06, and the final report should be available in the third quarter of FY06.

● **Fuel Subsystem Ballistic Vulnerability**—Plan and conduct gunfire tests against components of the OH-58D fuel supply subsystem to obtain a basic understanding of the potential for subsystem system disablement and fuel ignition. Testing will take place in the second quarter of FY06, and the final report should be available in the third quarter of FY06.

● **Rotor Control Subsystem Ballistic Vulnerability**—Plan and conduct gunfire tests against components of the OH-58D main and tail rotor control subsystem (mechanical and hydraulic) to obtain a basic understanding of the potential for subsystem degradation and disablement and system kills. Testing will take place in the second quarter of FY06, and the final report should be available in the third quarter of FY06.

■ **Helo Ordnance Vulnerability**—This project will investigate helicopter ordnance reactions to small arms, AAA, and fragments (FY05—2.75 in rockets) reported in OIF and OEF. Collateral damage to aircraft structure and weapon systems components will be identified, as will the operational consequences. Test results will be used to update component P(cd/h)s and structural kills. Testing will take place in the fourth quarter of FY05, and the final report should also be available in the fourth quarter of FY05.

■ **Apache Ammo Magazine**—Combat data from OIF and OEF indicate the Apache ammo magazine is particularly prone to fail if hit. Vulnerability studies often consider ammunition packs as armor. This project will identify potential ways to improve component hardness and performance when hit, determine if ammunition packs should be used as armor, obtain component P(cd/h) and other Modeling & Simulation (M&S) data for vulnerability analysis, and provide additional data for Apache Block II survivability analysis and evaluation. Testing will take place in the fourth quarter of FY05, and the final report should be available in the first quarter of FY06.

## Legacy System Product Improvement

Working with the Program Offices to address legacy issues (e.g., to identify and quantify legacy system vulnerabilities and verify legacy survivability enhancements).

■ **A-10 Warthog**—In FY05, two A-10 Warthog efforts were funded under JLF/Air: Dry Bay Foam Verification and Aft Fuselage Hardening.

● **Dry Bay Foam Verification**—The objective of this project is to test and validate the new dry bay foam used in the A-10 fuselage area by using a combination of airflow and ballistic testing. The formulation has changed for the A-10 wing and fuselage dry bay foam. The new foam formulation



Figure 3. JT9D Engine for MANPADS Test

has not been subjected to ballistic testing with airflow. The A-10 SPO is concerned with dry bay fire vulnerability. If this unproven dry bay foam is vulnerable to fire, the vulnerability must be identified, since the A-10's life has been extended to the year 2028. Testing will begin in the fourth quarter of FY05, and the final report should be available by the first quarter of FY06.

● **Aft Fuselage Hardening**—The objective of this project is to decrease the vulnerability of the A-10's flight control systems located in the aft fuselage. Since 1989, most of the A-10s lost in combat (5 of 7) were lost after a missile struck the back of the aircraft, damaging the aft fuselage and resulting in the loss of flight control. Several other aircraft lost all hydraulics and partial flight controls but were able to land safely. Both flight control systems (hydraulic systems A and B and the back up control cables) run through the narrow aft fuselage to service the flight controls in the empennage. This area is directly behind the engines and tends to be the target for IR missiles. Testing will begin in the second quarter of FY06, and the final report should be available by the fourth quarter of FY06.

■ **CH-53E Sea Stallion**—In FY04, JLF/Air entered the second year of a multi year investigation of the vulnerability of the CH-53E platform. In FY04, ballistic tests were conducted against CH-53E rotor and drive subsystems (main and tail rotor blades, pylon fold, tail drive shaft) under representative dynamic loads. These tests will be used to gather damage data and perform post damage operating endurance testing on dynamic components to evaluate the reduction or loss of dynamic flight load capability. CH-53E fuel system testing is planned for May and June 2005. The final report covering both phases of testing should be available by the first quarter of FY06.

■ **UH-60 Blackhawk**—In FY04 and FY05, three UH-60 efforts were funded under JLF/Air. Dry bay foam vulnerability reduction alternatives, Improved Durability Gearbox (IDGB) run dry ballistic vulnerability tests, and UH-60 engine nacelle fire extinguishing system effectiveness against ballistic threats. The results of these projects are applicable to all tri service H-60 aircraft and to future production variants, including the Army's UH-60M model.

● **Dry Bay Foam Vulnerability Reduction Alternatives**—The FY04 effort was conducted for detailed test planning and hardware acquisition. Preliminary research on existing information (data search) began in March

2004. The FY05 effort will be conducted for material acquisition, testing, and the final report. Testing will take place in the third quarter of FY05, and the final report should be available in the fourth quarter of FY05.

- **IDGB Run Dry Ballistic Vulnerability Tests**—The FY04 effort was conducted for detailed test planning and hardware acquisition. The FY05 effort will be conducted for material acquisition, testing, and the final report. Testing will take place in the third quarter of FY05, and the final report should be available in the fourth quarter of FY05.

- **Engine Nacelle Fire Extinguishing System Effectiveness**—Phase I of this effort was completed in FY02. Phase II testing and the Quick Look Report were completed in June 2004, with final report submission estimated for April 2005. Phase III testing was completed in January 2005. The final report covering all three phases should be available by the fourth quarter of FY05.

## Vulnerability Reduction Testing/Technology Insertion

Working with the Joint Aircraft Survivability Program (JASP) Vulnerability Reduction Subgroup and Program Offices to test technologies for vulnerability reduction developed by the JASP.

- **Enhanced Powder Panel Validation**—The objective of this project is to validate the design and effectiveness of the Enhanced Powder Panel (EPP), which is the final step in taking the proven technology from the laboratory and sub scale demonstrations to a full scale test and finally being ready to field. Current commercial powder panels are not always effective as a passive fire extinguishing device, and few alternatives exist to active fire suppression for aircraft dry bays. Previous testing has shown commercial

powder panels have a limited effectiveness range, detracting from their ability to be used in a wide range of applications. EPPs offer the potential to improve the effectiveness of passive fire extinguishing, providing a reliable and virtually maintenance free means of fire mitigation for aircraft dry bays. Baseline testing of these panels demonstrated their ability to increase powder release and provide better powder dispersion, longer dispersion periods, and greater design flexibility. In 2003, sub scale fire testing at the Naval Air Warfare Center Weapons Division (NAWCWD), China Lake, CA, demonstrated feasibility and effectiveness improvements over commercial powder panels. The current FY04 JASPO Vulnerability Subgroup project, "EPP Development," will conclude with an EPP design that is ready for production and has been demonstrated in smaller scale testing. However, testing on full scale aircraft is required to validate the production ready EPP and demonstrate its readiness to be fielded. Testing will begin in the fourth quarter of FY05, and the final report should also be available by the fourth quarter of FY05.

- **CH-47D Chinook**—In FY04, JLF/Air completed an effort in partnership with the Cargo Helicopter Program Manager (PM), the US Department of Defense (DoD), and commercial armor developers to design, manufacture, and qualify a shield that will reduce the probability of fuel fires resulting from small caliber projectile impacts on the engine's fuel feed shutoff valve located in the CH-47D rotorcraft. Sample armor panels were requested from three different armor manufacturers. The goal was to test both high carbon steel and ceramic armor tiles. Twenty five shots were completed in September 2004. Sixteen shots were completed for Phase I (coupon level) and nine shots for Phase II (on rotorcraft). Five types of armor were tested against two different threats. The final report should be available by the third quarter of FY05.

- **Predator**—In FY04, the JLF/Air Program planned to test the system vulnerability of a Predator's fuselage and subsystems' replica (fuel, propul-

sion, and control) before and after select vulnerability reduction features are in place. In keeping with the DDOT&E and LFT&E's desire to integrate more closely the JLF program to other DOT&E investment programs, shotlines for this effort will be based on the Computation of Vulnerable Areas and Repair Times (COVART) analysis previously completed under the Joint Aircraft Survivability Program's Predator Vulnerability Analysis (FY03). The Predator analysis identified potentially vulnerable areas in the current Predator design that can be addressed in future versions. This project directly supports the UAV Program Office in identifying improvements in vulnerability reduction that can be made to present or future blocks of the aircraft. These lessons learned can be applied to other UAVs and to Unmanned Combat Air Vehicle (UCAVs). Testing will begin in the third quarter of FY05, and the final report should be available by the fourth quarter of FY06.

## Emerging Threats of Interest

Working with the Intel Agencies, User Commands, and Program Offices to address emerging threats of interest.

- **Rocket Propelled Grenade (RPG)**—As we have seen in recent armed conflict, our front line rotorcraft systems are susceptible and vulnerable to attack from the Rocket Propelled Grenade (RPG). The JLF/Air FY04 Program investigated the vulnerability of front line rotorcraft to this threat by testing AH-1S Cobra aircraft. The goal of this effort is to understand the damage mechanisms of this threat and identify potential survivability enhancements for rotorcraft. This multi year, tri service program was completed in March 2005. The staff of the Survivability/Vulnerability Information Analysis Center (SURVIAC) is authoring a combined final report, which should be available by the third quarter of FY05.

- **Man Portable Air Defense Systems (MANPADS)**—In FY04, JLF/Air initiated a multi year effort to investigate the vulnerability to MANPADS of the CF6

large turbofan engine. The following long standing issues will be addressed:

- (1) What is the inherent vulnerability of an operational CF6 engine hit by a MANPADS?
- (2) How does the hit point and damage state compare to pre test predictions?
- (3) How does the damage affect engine operation and thrust?
- (4) How will the thrust alteration affect safety of flight?
- (5) If damage produces a kill, what is the kill mechanism?

Test results from this effort will support large aircraft operational risk assessments and vulnerability analyses that will lead to improved warfighter protection. The results of large engine characteristics to MANPADS impact and detonation identified during this effort will be used to feed future large engine design and evaluation requirements. Test planning occurred in FY04, testing will occur in late FY05 and FY06, and the final report should be available by the end of FY06.

In FY05, JLF/Air initiated an effort with the National Aeronautics and Space Administration (NASA) designed to assess MANPADS damage expectations on control surfaces, which will help identify the magnitude of the MANPADS problem relative to large military and commercial aircraft. The following long standing issues will be addressed:

1. What is the inherent vulnerability of large aircraft control surfaces to MANPADS?
2. How will the damage affect safety of flight?
3. What is the risk of aircraft damage presented by the Aim Point Biasing Infrared Countermeasures (IRCM) concept?



Figure 3. H-60 Engine Nacelle Test Setup

Data generated from this effort will validate MANPADS aircraft damage models and will support the low vulnerability role in layered, counter MANPADS protection concepts. Testing will occur in late FY05 and FY06, and the final report should be available by the close of FY06.

In summary, because the US military is purchasing fewer and more expensive weapon systems, and because the US military is extending the life of fielded weapon systems beyond their intended life spans, aircraft survivability has become a "critical system characteristic" and has emerged as a distinct and important design discipline. Top level guidance in survivability design is prescribed; quantified requirements for the susceptibility and vulnerability of aircraft are now routinely specified; methodologies for assessing aircraft susceptibility and vulnerability now exist; and testing for survivability is mandated. Given today's multifaceted global threat environment, combined with the continuously evolving cat and mouse game of threat vs. countermeasure, the first step in understanding aircraft survivability is to understand how these threats affect the aircraft when all countermeasures fail and an aircraft gets hit. The JLF/Air Program continues to provide a valuable avenue for testing the vulnerabilities and vulnerability reduction equipment developed for currently fielded US aircraft.

## About the Authors

Mr. Jeffrey Wuich, an associate at Booz Allen Hamilton, working in support of the SURVIAC, provides technical and administrative support to the JLF/Air. Mr. Wuich has over 14 years of aerospace survivability experience. Jeff received his Bachelor of Science in Aerospace Engineering, from Iowa State University in 1988, and his Master of Science in Mechanical Engineering, from the University of Dayton in 1992. He is a member of the National Defense Industrial Association (NDIA). He may be reached at 937.255.3828, x259 (DSN 785.3828, x259), or by e-mail at [wuich\\_jeff@bah.com](mailto:wuich_jeff@bah.com).

Mr. John Murphy has more than 21 years of aerospace survivability experience and is currently the Technical Director of Aerospace Survivability and Safety Flight (46 OG/OGM/OL-AC). Since 1997, he has directed numerous Joint Live Fire Aircraft Systems (JLF-Air) programs, and since 2001, he has been the Joint Test Director for JLF Air. He also served as the Air Force Deputy Test Director for JLF-Air from 1997–2001. Mr. Murphy received a BS degree in Mechanical Engineering from the University of Cincinnati in 1986 and an MS degree in Mechanical Engineering from the University of Dayton in 1991. He may be reached at 937.255.6302, x233; DSN 785.6302, x233; or by e-mail at [john.murphy@wpafb.af.mil](mailto:john.murphy@wpafb.af.mil)

ly 0.3 psig at 38,000 ft, it can be seen that at both altitudes the non vented data is approximately 42 times that of the vented pressure results. This data also shows that the ullage oxygen concentration has little or no effect on the resulting pressure rise from ignition, and that the ratio of differential to initial pressure does not vary considerably with either altitude or oxygen concentration.

### Further Testing

The FAA's LOC testing has improved the cost effectiveness and feasibility of a commercial aircraft OBIGGS. However, further studies into fuel tank flammability continue, which are designed to improve existing models that could predict the progression of flammable vapors in a fuel tank over the course of a flight. These models are currently being validated and improved through the use of both laboratory and flight test data. More information on the FAA's fuel flammability research and other fire safety research programs can be found online at [www.fire.tc.faa.gov](http://www.fire.tc.faa.gov).

### About the Author

Steven M. Summer works at the Federal Aviation Administration (FAA) Technical Center's Fire Safety Branch as a project engineer in charge of its fuel-tank flammability program in support of aircraft fuel-tank protection Research & Development (R&D) efforts. He is the author of several technical reports dealing with fuel-tank flammability and has presented his research findings at numerous international conferences, including those of the International Aircraft Systems Fire Protection (IASFP) Working Group. He received his BS and MS in Mechanical Engineering from Rutgers University. He attended graduate school under a fellowship grant, where he performed research to determine several key flammability characteristics of JP-8 fuel in an effort to further the knowledge base of aircraft fuel-tank flammability.

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# Survivability Initiatives for Unmanned Aerial Vehicles (UAVs)

■ by Pete Bartolomeo

Unmanned Aerial Vehicles (UAVs) have been in use for decades. They were originally designed to be inexpensive, expendable aircraft, and survivability was not a factor in their design. In recent years, however, UAVs have become more sophisticated in their design and their missions. They are now extremely valuable assets to the warfighter, providing essential information on the battlefield. Also, UAVs have increased considerably in cost, some reaching well into the multi-million dollar range. Because of these factors, many UAVs are no longer considered expendable.

With this concept of non-expendable UAVs, it is necessary to increase their survivability. In recent years, the Joint Aircraft Survivability Program Office (JASPO) has sponsored two projects to achieve this goal: "Miniature Radar Warning Receiver for UAVs," and "Acoustic Reduction for UAVs."

## Miniature Radar Warning Receiver for UAVs

In future conflicts, as UAVs' missions become greater in number and more complex, they will be flown into hostile areas protected by radio frequency (RF) threats. This is not an environment against which most UAVs can defend themselves. The Naval Air Systems Command (NAVAIR) Survivability Division worked with BAE Systems, Nashua, NH, to develop a low-cost, lightweight Radar Warning Receiver (RWR) that meets the strict size, weight, and power constraints of small, unmanned aircraft. This RWR came to be known as the "Puffer."

The Puffer detects and identifies threat radars, the quadrant of arrival, and the received power of the signal. The specific ID of the threat radar, the quadrant, and the received power level are

fed into the UAV's standard transmitter and sent in real time to operators at the ground station. The Puffer is capable of detecting both Pulsed-Waved (PW) and Continuous-Wave (CW) radars.

The Puffer RWR could conceivably be used in two different ways. The first would be to increase the situational awareness of the UAV that is carrying it. This is especially important for larger UAVs that must be concerned with being targeted by an RF threat. The Puffer will permit an operator to detect when an aircraft is in danger and to make a decision as to the best course of action. The second use of the Puffer would be to increase the situational awareness of other friendly aircraft in the area, both manned and unmanned. For instance, a UAV could scout a hostile area that is too dangerous to be explored by manned aircraft. The Puffer would detect the RF threats in the area and report these threats and their approximate location to an operator in real time. This information could then be immediately passed on to commanders on the ground or in the air.

What sets the Puffer apart from other RWRs is its small size, weight, and power consumption. In its current configuration, used for testing, it is a rectangular box measuring 10 in x 7 in x 2 in. The Puffer system itself weighs 2.7 lbs, not including packaging and mounting hardware. A complete system could be designed to weigh approximately 4 lbs, and it can be easily modified to fit different UAVs. The system draws 17 watts while operating.

The Puffer has been flown on the AeroLight UAV and has completed two successful flight tests at the China Lake, CA, Electronic Combat Range. Work began this year to upgrade the Puffer's capability to include detection of Millimeter-Wave (MMW) threats, with a flight test planned for FY07.

## Acoustic Reduction for UAVs

UAV squadrons in theater are currently facing difficulties caused by the amount of noise produced by their UAVs. Both Pioneer and Shadow squadrons have reported that, in many situations, they



Figure 1. AeroLight with Puffer II

cannot get as close to their targets as desired without alerting an enemy to their presence. To remain undetected, the UAV is forced to remain at a distance, which doesn't permit the payload (e.g., camera) to be used at full effectiveness. Making the UAV quieter would have a significant positive impact on missions. The UAV could fly closer to the target, take a more accurate and detailed video, and send more useful information back to the troops who rely on it.

Over the years, significant work has been performed on reducing the acoustic signatures of large aircraft, but not much of this work has been applied to the UAV community. Funded by JASPO, NAVAIR's Survivability Division examined ways to test, measure, and improve the acoustics of UAVs.

The first task was to choose a UAV and take some baseline measurements. NAVAIR chose to measure the AeroStar, a UAV very similar to the Pioneer. In 2003, it was transported to Eglin Air Force Base, FL, to take advantage of Acoustic Week. This was a large, multi-service event that offered many different groups an opportunity to share the costs of performing acoustic measurements on their respective aircraft.

For this test, the AeroStar flew several passes over an array of microphones set up to record the noise emitted in azimuths around the aircraft. The test data was analyzed in both time and frequency domains to give detailed knowledge of the acoustic signature of the UAV. It is important to analyze the frequency of the noise, because the human ear is more sensitive to a certain range of frequencies and because the sound's propagation through the atmosphere is highly dependent on its frequency.

After the AeroStar measurement, NAVAIR teamed with the Army Research Lab to take advantage of an opportunity to measure the acoustic signature of a unique UAV produced by DRS Unmanned Technologies. It uses the same engine as the AeroStar, but a muffler had been added to it and the propeller had been geared down so that it turned at a slower rate than the engine. This enabled the test team to separate the noise produced by the engine from that of the propeller, which was not possible on the AeroStar. The results of this test will be included in the project final report that is scheduled for release at the end of 2005.

Taking advantage of this opportunity, NAVAIR will be able to make recommendations about the effectiveness of noise suppression techniques on UAVs, which, in turn, will lead to increased survivability and improved mission effectiveness in the future.

### About the Authors

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Figure 2. Aerostar landing



# Influence of Unmanned Aircraft System (UAS) Survivability on System Life Cycle Cost

■ by Dr. Gregory J. Born, David H. Hall, and Charles M. Pedriani

## Introduction

Unmanned Aircraft Systems (UAS) are being considered for an ever widening range of missions, which has resulted in a growth of platform types and quantities, mission roles and equipment, and expanding operating environments. Because of system cost and/or mission criticality, survivability is becoming an important system attribute for many of these applications. As the trade space for survivability grows, approaches are required to guide developers to the best survivability solution for a given platform, mission, and threat or operational environment. This article is an overview of the methodology that SURVICE Engineering Company has been developing to assist decision makers in identifying the survivability alternatives that provide the lowest life cycle cost while meeting the operational requirements.

## Background

It is a common misconception that adding survivability enhancements is always better. Adding survivability features may save more assets in a hostile environment; however, that may not translate to saving cost. This dilemma is at the core of survivability decisions for manned aircraft, where bringing home more aircraft is always "good" because it saves lives. But we cannot usually afford all the survivability features that are available. So the question is, "When do we stop?" This becomes a difficult decision when lives are in the balance. However, because there is no aircrew to consider, unmanned aircraft have a calculable cost, and sooner or later the cost of adding more survivability features outweighs their cost benefit to the platform. This assumption, shown in Figure 1, is at the heart of the methodology described in this article.

## Methodology Description

The survivability cost benefit methodology, shown in Figure 2, includes four steps: gathering system information, developing operationally representative vignettes, modeling the vignettes in a mission level model, and computing the life cycle cost.

### Gather System Information

Information is required on the performance and cost of a basic platform, its proposed survivability enhancements, and its mission package. Because these three groupings align with the view most developers have of a system, they are useful for evaluating the various alternatives to system survivability. However, the methodology accounts for the fact that survivability may be enhanced or degraded not only by specific survivability features but also by the performance of the platform or the mission package.

Gathering information to use in the analysis can be a difficult task, particularly if the platform design is immature. However, the methodology can be applied early in the program by using engineering judgment and parametric analysis. Those early answers will be more suitable for rela-

tive evaluations, sensitivity studies, and requirements analysis. As more specific information becomes available about missions, threats, and configurations, the inputs to the methodology can be refined to provide a more definitive assessment of the impact of survivability enhancements.

### Develop Vignettes

It is essential that system vignettes be developed that accurately represent the operational environment, mission, threat forces, friendly forces, and the UAS interaction with these factors. In a low threat environment, even modest investments in survivability may not be cost effective; however, in a high threat environment, investments in survivability can have a dramatic impact on life cycle cost. Consequently, arriving at life cycle cost requires knowledge of the UAS, supporting systems, and the ways in which they interact with the threat. Synergistic effects on total system costs must be accounted for among threat, mission, platform performance, mission equipment, and survivability enhancements. Several different vignettes will likely be required to represent the anticipated uses of the system, and weighting factors for these vignettes may be useful.

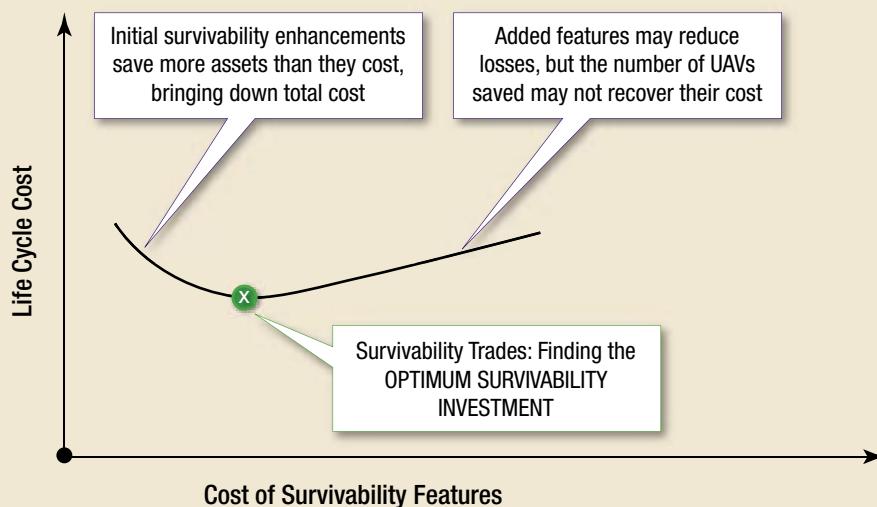


Figure 1. Survivability influence on life cycle cost

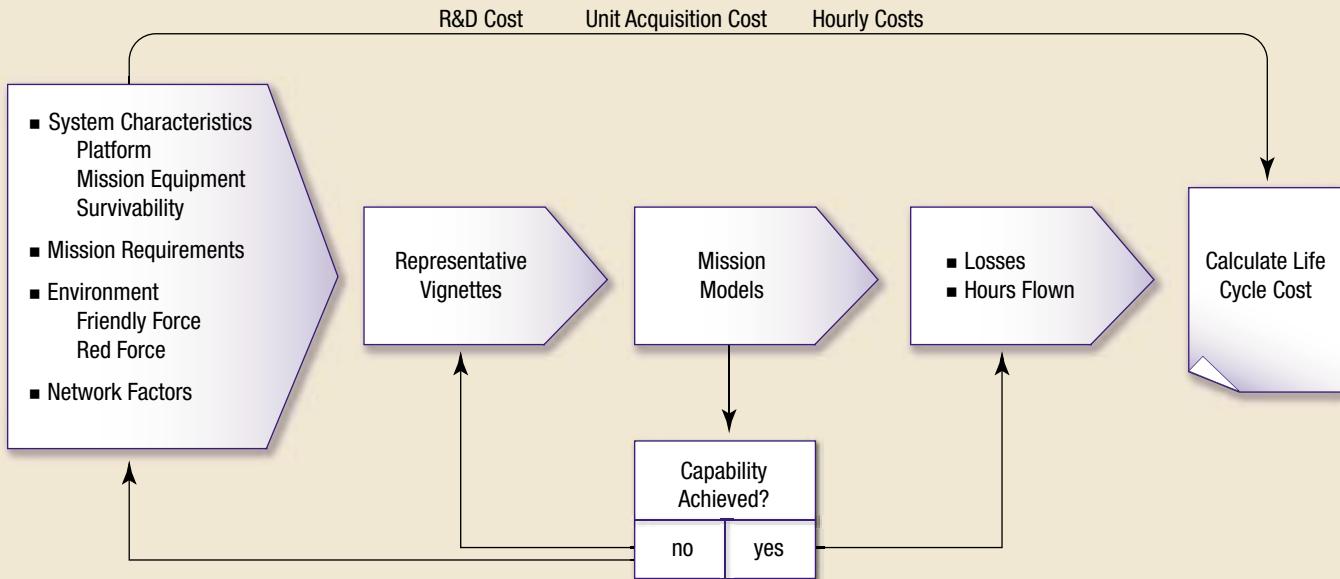


Figure 2. Life cycle cost assessment methodology

### Analyze Vignettes

Survivability analysis of the vignettes generates two parameters that are required for the cost calculation: the number of losses and the number of flight hours to complete the mission. Losses affect acquisition cost, and hours flown affect Operations & Support (O&S) costs. We found that mission level models provide a good compromise between the fidelity required for these parameters and the resources required to build the simulation.

Mission level models have other advantages beneficial to this methodology. A single model generates the survivability information required for cost estimates. Therefore, there is no need to manage information flow between survivability models, and the inputs and assumptions remain transparent. Also, parametric analyses can be used to mitigate the absence of specific information, especially early in the acquisition process.

It is true that mission models can require significant investment in resources and voluminous input data, but these models also usually include defaults that can be used when resources or input information are lacking. Because any shortcomings are transparent, the simulation can still be useful, particularly early in the program, when numerous runs may be

helpful in reducing the number of candidate configurations. The setup time can also be minimized by prudent design of the vignettes and by leveraging data from previous analyses.

### Compute Life Cycle Cost

For the relationship in Figure 1 to be valid, life cycle cost must include development, acquisition, and O&S costs for a fleet large enough to perform the mission in the anticipated environment over the life span of the system. To simplify the cost analysis, we have purposely ignored disposal cost as a part of life cycle cost. The survivability features addressed in the assessment should include anything that permits the asset to complete the mission and come home, such as mission planning, aircraft performance, situational awareness, hardening, Countermeasures (CMs), off board assets, and stealth technology.

We segregate costs attributed to the basic platform, the mission package, and the survivability enhancements. Each element includes parameters that influence the results of the survivability analysis. We created a spreadsheet that calculates the life cycle cost from the various cost elements and the information obtained from the survivability analysis.

### Sample Case

The methodology was demonstrated by analyzing the survivability alternatives for a notional UA rotorcraft performing reconnaissance in a relatively high threat environment. The survivability features chosen for evaluation were infrared (IR) signature reduction and several notional IR Countermeasures (IRCMs). Size and performance for the notional unmanned aircraft (UA) were similar to the Navy's Vertical Tactical Unmanned Aerial Vehicle (VTUAV). The cost assumptions are fictional and for illustrative purposes only.

### Scenario Description

The threat for the UAS scenario was extracted from the unclassified Obruty war final battle scenario that is distributed with the Joint Integrated Mission Model (JIMM) that we used for this example. The threat consists of three batteries of short range, radar directed Surface to Air Missile (SAM) systems and the battalion commander. The battalion commander has medium range acquisition radar and communications equipment. Also present were radio frequency (RF) SAM systems and IR guided Man Portable Air Defense Systems (MANPADS).

The friendly force in this scenario is assumed to involve three VTUAV systems. Each system consists of three rotary wing UA and a ground control station.

Each UAS is assigned a threat area for surveillance, and the flight paths were defined randomly. When a ground target is detected, the UA will transmit the imagery to the ground control station. We have also assumed that there are ground attack aircraft on station that receive target assignments from the ground controller and reactively fly to the target(s) to deliver Joint Direct Attack Munitions (JDAM).

## Survivability Analysis Results

The average values of shots fired and UA hit are presented in Table 1 for signature sensitivity and in Table 2 for CM effectiveness. These survivability characteristics were evaluated separately. As shown, the number of RF missile shots and hits is relatively constant over all variations. There are relatively few RF missile shots compared with IR missile shots. This is a consequence of the command and control, Emission Control (EMCON) discipline, and the logic for making target assignments. The data for these tactics were extracted from the JIMM Obruty war final battle scenario and were not modified for this analysis.

The results of the signature analysis showed no significant improvement in survivability until the signature level fell to 1.0 watt per steradian (W/sr). The sig-

Table 1. Attrition results for the UA as a function of signature

SIGNATURE	RF Shots	IR Shots	RF Hits	IR Hits
500 W/sr	2.43	17.10	0.93	4.33
50 W/sr	2.80	16.50	0.87	4.50
5 W/sr	2.33	16.87	1.00	4.63
1 W/sr	1.93	6.43	1.00	1.73

Table 2. Attrition results for the UA as a function of CM effectiveness

CM	RF Shots	IR Shots	RF Hits	IR Hits
None	2.43	17.10	0.93	4.33
Option 1	2.57	18.50	0.93	3.87
Option 2	2.13	19.70	1.00	3.30
Option 3	1.97	21.70	0.97	2.00

nature levels used for this analysis span two orders of magnitude, because we had no open source data against which to benchmark a helicopter signature. However, there is a distinct improvement in survivability with each increase in the notional CM effectiveness.

## Life Cycle Cost Calculation

We made estimates for the cost elements associated with the development acquisition and operation of the fictional UAS and applied the survivability analysis results to obtain life cycle cost. We assumed a total of 90 missions, consisting of 10 sorties of nine UA, and a time

frame of six hr for each UA to complete its mission. The initial fleet size was assumed to be 100, and we assumed that all lost aircraft were to be replaced.

Figure 3 shows that our fictional configuration with an IR signature of 1.0 W/Sr had the lowest life cycle cost. Note that it had the highest unit cost but far fewer losses than the other versions. This figure also shows that a signature level of 5.0 W/sr was the highest life cycle cost because it failed to reduce losses enough in the selected vignette to offset the cost to achieve this nominal signature reduction.

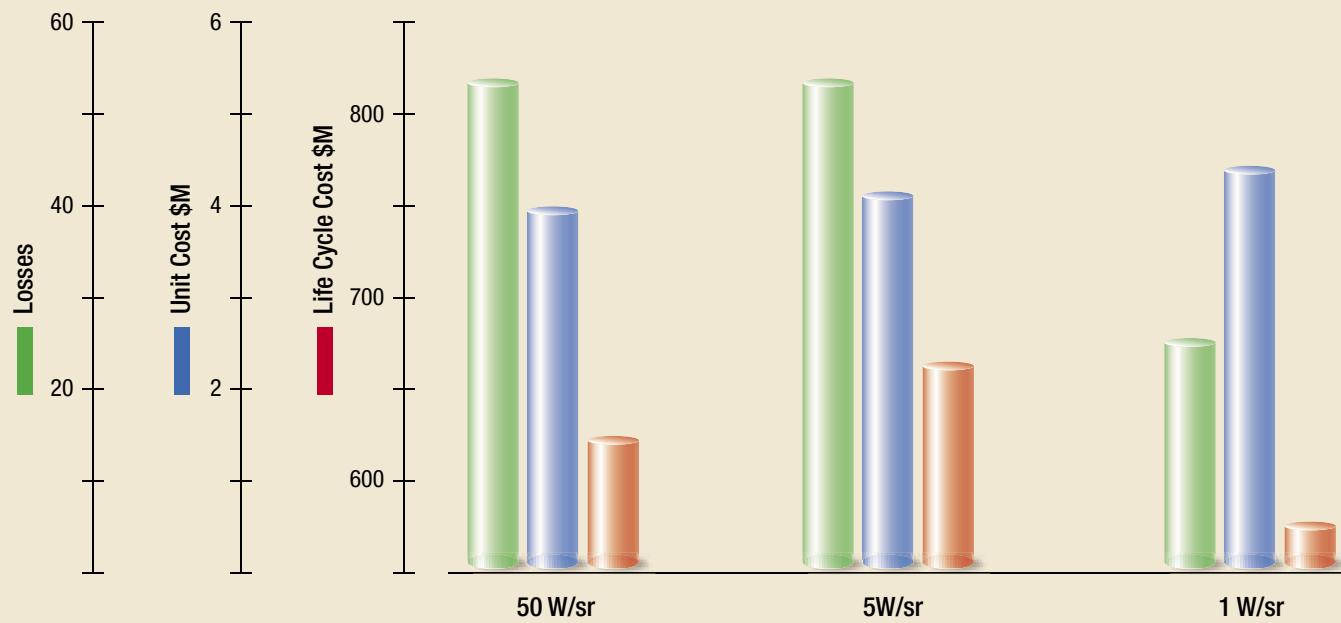


Figure 3. Effects of signature reduction on life cycle costs

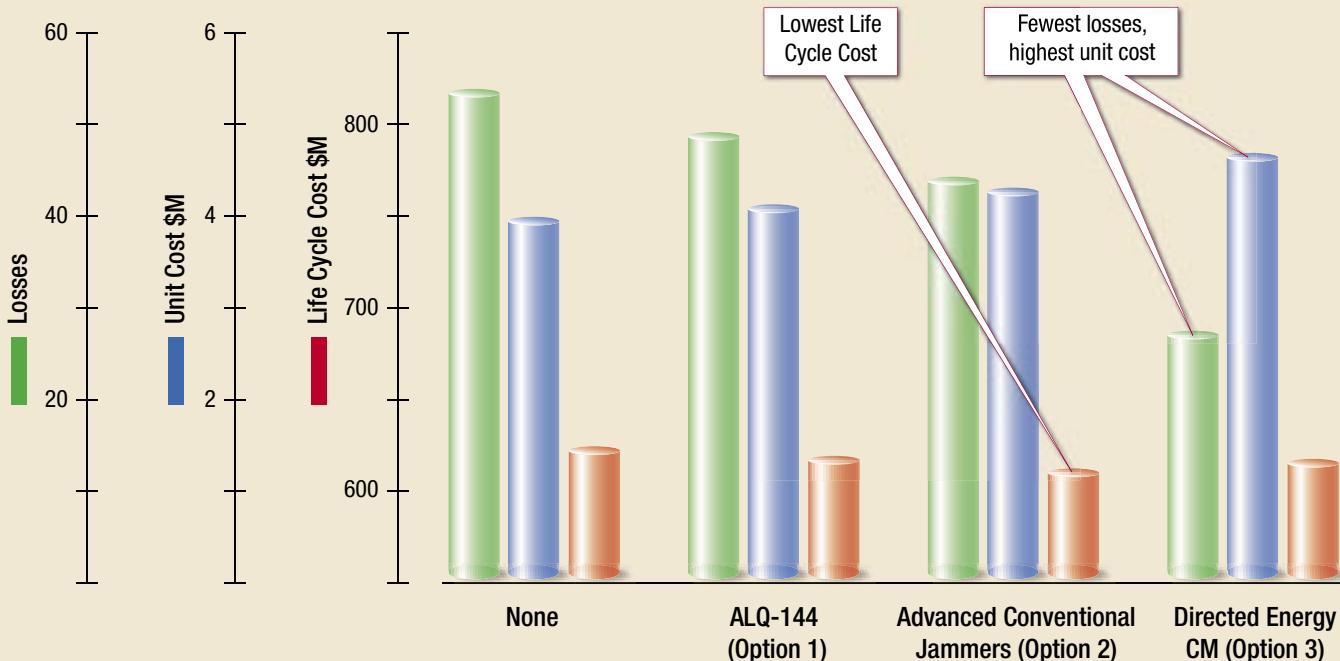


Figure 4. Effect of CM effectiveness on life cycle costs

Figure 4 indicates that even small improvements in CM effectiveness reduce life cycle cost to a degree. Although the directed energy CM resulted in the fewest losses, it did not offset the somewhat higher unit cost associated with that system.

## Summary

UAS are evolving from inexpensive combat adjuncts to technically sophisticated assets that perform critical combat missions under adverse conditions. UAS costs are spiraling upward, and the lives of our soldiers increasingly depend on successfully completing UAS missions. To protect these important and expensive assets, their survivability characteristics must likewise evolve from an afterthought to a fundamental and integrated consideration in their development and use.

The methodology presented in this article is a useful tool for UAS designers and decision makers. It provides a systematic approach to developing the synergistic relationships between UA system survivability, other design attributes, the environment, the anticipated combat function, and life cycle cost. This insight is essential to developing UASs that are both survivable and affordable.

The SURVICE Engineering Company will continue to improve the process and to advocate its use in the UA community.

## About the Authors

Dr. Gregory J. Born is a Senior Scientist at SURVICE Engineering Company's Ridgecrest Area Operation, providing model validation and accreditation support to the Joint Accreditation Support Activity (JASA) at the Naval Air Warfare Center, Weapons Division (NAWCWD), China Lake, CA, and analytical services to the NAWCWD Survivability Division. Dr. Born has conducted extensive validation on a number of survivability Models & Simulations, and he has analyzed and tested the susceptibility and operational effectiveness of a number of air vehicles. He is currently the Verification & Validation (V&V) Policy Director for the Joint Strike Fighter program. Dr. Born received a PhD in Theoretical Chemistry and Chemical Physics from the University of Florida and a BS in Chemistry from Southern Illinois University.

David H. Hall is the Chief Analyst for the SURVICE Engineering Company and deputy Manager of the Ridgecrest Area Operation. Before joining SURVICE, he was the Chief Analyst of the NAWCWD Survivability Division,

head of the Survivability Analysis Branches, Chairman of the Survivability Methodology Subgroup for the Joint Aircraft Survivability Program Office (JASPO), and interim JASA Director. Mr. Hall holds BS and MA degrees in mathematics from California State University, Long Beach, CA.

Charles M. Pedriani is principal investigator and team leader for SURVICE Engineering Company in projects involving susceptibility reduction, survivability design, system requirements, vulnerability reduction, and live fire testing. Mr. Pedriani currently provides support to JASPO on tasks to improve Joint Aircraft Survivability Program (JASP) planning activities. He was a team leader and product manager for the Army's Aviation Applied Technical Directorate at Ft. Eustis, VA, where he participated in numerous advanced technology programs. Mr. Pedriani holds a BS in Mechanical Engineering from Pennsylvania State University.

# Calendar of Events

## NOV

### 14–16, Belcamp, MD

BRL-CAD Introductory Training Course  
SURVICE Engineering Company: 410.273.7722  
[www.bahdayton.com/surviac/PDF/BRLCAD%20Meeting%20Info%202005.pdf](http://www.bahdayton.com/surviac/PDF/BRLCAD%20Meeting%20Info%202005.pdf)

### 14–18, Vancouver, Canada

2005 22nd International Symp on  
Ballistics NDIA  
[nmundy@ndia.org](mailto:nmundy@ndia.org)

### 16–17, Nellis AFB, Nevada

Winter Joint Aircraft Survivability  
Program (JASP) Joint Model Users  
Meeting (JMUM)  
SURVIAC: 937.255.3828 x273  
[jeng\\_paul@bah.com](mailto:jeng_paul@bah.com)

### 17–18, Belcamp, MD

BRL-CAD Users Group Meeting 2005  
SURVICE Engineering Company: 410.273.7722  
[www.bahdayton.com/surviac/PDF/BRLCAD%20Meeting%20Info%202005.pdf](http://www.bahdayton.com/surviac/PDF/BRLCAD%20Meeting%20Info%202005.pdf)

## JAN

### 9–12, St. Reno, NV

44th AIAA Aerospace Sciences  
Meeting and Exhibit  
[www.aiaa.org](http://www.aiaa.org)

### 31 Jan–2 Feb, Monterey, CA

Strategic and Tactical Missile  
Systems Conference  
[www.aiaa.org](http://www.aiaa.org)

## MAR

### 20–24, Washington, DC

Missile Defense Conference and Exhibit  
[www.aiaa.org](http://www.aiaa.org)

## APR

### 9–12, Nashville, TN

AAAA Annual Convention

### 10–13, Destin, FL

Aircraft Stores Compatibility Conference

### 17–20, Washington, DC

The 7th Annual BlazeTech Course:  
Aircraft Fire and Explosion  
Protection Against Accidents And  
Combat/Terrorist Attacks  
Albert Moussa, Ph.D., P.E: 617.661.0700 x 10  
[firecourse@blazetech.com](mailto:firecourse@blazetech.com)

Information for inclusion in the  
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